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# AN EXPLANATORY STUDY OF THE DENSITY AND ANNUAL RING WEIGHT IN FAST-GROWTH CONIFEROUS WOODS IN BRITISH COLUMBIA

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by

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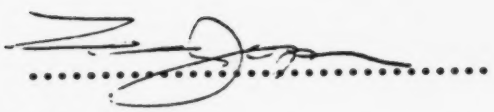

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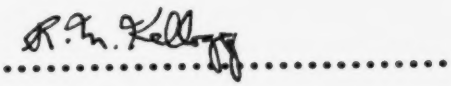

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## SUMMARY

Fourteen sampling sites were selected (for five commercially important species) with the help of Industry and Ministry of Forests foresters in both the Coastal and Interior regions of B.C. The species were Douglas-fir (both coastal and interior forms), western hemlock, lodgepole pine, Interior spruce (white or Engelmann), and western red cedar. Five trees were sampled at each site. A total of five cross-sectional discs were cut from each tree, one at breast height (BH) and four others at one-fifth intervals of total height.

Average yearly ring density trends were examined by X-ray densitometry from pith-to-bark at each sampling height and from BH to 80 percent sampling height. The inner core of juvenile wood (first 15 years of growth) was examined and its density was compared to the outer mature wood. Yearly development of stem-wood density and entire annual ring weight patterns were examined from age one to sampling age (35-105 years).

Within-ring density variation was the greatest, with three- to four-fold differences in magnitude, between earlywood and latewood. Within-tree average ring density variation was about 10 to 40 percent due to juvenile-mature wood differences. Between-tree variation of cumulative stem-wood density was about 20 percent and the trees could be ranked reliably according to density by about age 15 at each site for the five species studied. Based on arbitrary density levels in Douglas-fir, the mature wood extended from the base of the stem to about the base of the live crown. Douglas-fir showed a great diversity in average stem-wood density (0.38-0.54 $g/cm^3$), and in density distribution in the stem-wood which was thought to be biogeoclimatically induced. A high degree of uniformity was observed in juvenile wood density of Douglas-fir from the base to the top of the stem. Entire annual ring weights provided a good measure of stem-wood biomass productivity.

Juvenile wood was produced by the trees studied when the cambium was biologically young in age (up to about 15 years). Therefore the crown portion of older trees still produced juvenile wood, resulting in an inner cylinder of wood extending from the base to the top of the stem. Annual rings close to the pith tended to be wide with comparatively high density wood for the first three to five rings. Low density juvenile wood was found in Coastal Douglas-fir and western hemlock. Interior dry belt Douglas-fir and lodgepole pine has less pronounced low density juvenile wood. The first 15 years of growth of Interior spruce and wet belt Douglas-fir and Coastal western red cedar resulted in relatively high density in respect to their mature outer wood. The Coastal sites were more vigorous biomass producers (as expressed by entire annual ring weights in the stem-wood) than the Interior sites.

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## 1.0 INTRODUCTION

Certain challenges will be posed to the forest products industry of Western Canada by the application of intensive forestry practices in future forests. In such forests, trees may be grown from genetically improved seed stock and be subjected to spacing, fertilization, pruning, and thinning. Accelerated growth and earlier harvest will lead to a greater proportion of juvenile wood in lumber and other solid wood products as well as in pulp. The technical properties of juvenile wood may be different from those of mature wood and may affect the utilization of the material in many important ways. It is essential that industry identify these problems and make plans to accommodate them.

The objective of this study was to characterize the properties of fast-grown coniferous woods in British Columbia in an exploratory way and thereby to identify the most serious wood quality problems industry will encounter in the utilization of trees from the future intensively managed resource. Specifically, attention has been focussed on the properties and extent of juvenile wood in Douglas-fir (both Coastal and Interior forms), western hemlock, lodgepole pine, Interior spruce, and western red cedar.

## 2.0 STAFF

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## 3.0 BACKGROUND AND LITERATURE REVIEW

An excellent analysis of the relevant literature concerning wood properties of improved trees grown under intensive management was prepared by Bendtsen (1978). One can only support his conclusions that the difference between wood properties of trees from old growth and rapidly grown intensively managed forests are associated with the

short rotation and resulting high proportion of juvenile wood in the harvested resource. He reviewed the generalized properties of juvenile wood and the problems encountered in processing and utilizing juvenile wood in solid wood products.

There is a limited amount of information on the properties of juvenile wood for the coniferous species in British Columbia. Douglas-fir is the exception; we are fortunate in having substantial information available for this species. A number of authors have observed the lower juvenile wood specific gravity relative to mature wood (Gerhards, 1978; Barrett and Kellogg, 1984; Kennedy and Warren, 1969; Reck and Sziklai, 1973; Littleford, 1961; Senft et al., 1985; Wellwood and Smith, 1962). The reduced strength properties of Douglas-fir juvenile wood relative to mature wood have been reported by Barrett and Kellogg (1984), Gerhards (1978) and Littleford (1961).

Less information is found in the literature relative to the juvenile wood properties of western hemlock. Wellwood and Smith (1962) and Krahmer (1966) have shown evidence that the pith to bark density pattern for western hemlock is quite different from that of Douglas-fir. For this species specific gravity was highest for wood near the pith, then it decreased sharply towards the bark. Krahmer (1966) found that this sharp decrease tended to occur within the first two inches from the pith. At distances beyond two inches from the pith, particular trends of increasing or decreasing specific gravity were not evident. It would appear, however, from both the trees for which he illustrated data, and the average data for 94 young hemlock trees presented by Wellwood and Smith (1962), that at lower height positions there is a gradual increase in specific gravity with increasing age.

Wang and Micko (1984) and Taylor et al. (1982) have reported on variation in specific gravity and tracheid length in white spruce in Alberta. In some areas a high corewood specific gravity was found. In others, although the first five years of growth might have a somewhat higher values than wood produced subsequently, corewood specific gravity is generally not as great as that of the mature wood.

The same authors, Taylor et al. (1982) have studied the variation in specific gravity and tracheid length in lodgepole pine in Alberta. They found that at both breast height and the four meter height position, specific gravity decreased from the first to the second five year segment from the pith and then increased to a maximum between 30 and 50 rings from the pith. At higher positions within the tree a trend develops in which many trees show a trend of decreasing specific gravity with increasing numbers of rings from the pith.

Harris (1971) observed the variation in a number of the physical properties of the wood of 20-30 year-old lodgepole pine grown in New Zealand. Using a beta ray densitometer, he was able to record radial patterns of maximum, minimum, and mean density of trees from sites under various levels of physiological stress. Maximum density values increase abruptly from pith outwards and then reach a level that remains relatively constant. Maximum density values vary widely from

ring to ring, probably reflecting the year to year effect of climatic variation of latewood development. Maximum density was lower on cold sites than on warm ones. Minimum density values usually decrease over the first two to four rings and then remain relatively constant. Minimum density tends to remain lower in the outer wood of fast-grown trees compared to slow-grown trees. Mean ring density patterns vary from site to site, but show a general pattern similar to that found by Taylor et al. (1982); that is, a decline in density for the first few rings from the pith, followed by an increasing density trend with age. Trees from the fastest growth site showed a pattern of continuously declining mean ring density from pith to bark. This implied that under fast growth conditions a proportionately greater amount of the ring was earlywood rather than latewood.

## 4.0 MATERIALS AND METHODS

### 4.1 SITE SELECTION AND SAMPLING

Fourteen sampling sites, six Coastal and eight Interior, were selected with the help of industry and Ministry of Forests foresters. Five study species with fast growth rates (average ring width about 5 mm) were examined in this study:

1. Douglas-fir, Pseudotsuga menziesii (Mirb.) Franco;
2. Western hemlock, Tsuga heterophylla (Raf.) Sarg.;
3. Lodgepole pine, Pinus contorta Dougl.;
4. Interior spruce, (white) Picea glauca (Moench) Voss or (Engelmann) Picea engelmannii Parry;
5. Western red cedar, Thuja plicata Donn.

For Interior Douglas-fir and Coastal western red cedar, two different fast-grown conditions were sought. In the first one, growth was rapid from the time of establishment of the stand. In the second, growth was rapid following release due to a selection cutting after a long period (20-60 years) of slow growth. In the case of Coastal western red cedar, one site was selected for each fast growth condition while for Interior Douglas-fir, two sites were selected for each (fast and released). Table 1 lists the five species sampled, sampling sites, location, collection date, forest section in the Coastal and Montane Forest Region and appropriate biogeoclimatic zone according to Krajina (1973). Figure 1 is a map showing sampling sites on Vancouver Island and Interior B.C.

The above five species were chosen for the study because of their commercial importance and relatively wide distribution range. Sampling was undertaken on four separate occasions in 1983-84. In each case site selection was made through extensive reconnoitering,

Table 1

List of Species Sampled, Site Name and Location
Date of Sampling, and Other Information

| Species | Site No | Site Name | Coordinates latitude | Coordinates longitude | Collection Date | Forest Section** | Biogeoclimatic Zone |
|---|---|---|---|---|---|---|---|
| Douglas-fir | 1 | Jordan River | 48°26'30" | 124°02'00" | June 21, 1983 | Northern Pacific Coast | Coastal western hemlock |
| | 2 | Copper Canyon | 48°50' | 123°47' | June 22, 1983 | Strait of Georgia | Coastal Douglas-fir |
| | 3 | Heffley | 51°01' | 120°10' | June 26, 1984 | Central Douglas-fir | Interior Douglas-fir |
| | 4 | Heffley R* | 51°01' | 120°10' | June 27, 1984 | " " | " " |
| | 5 | Galena R* | 51°38' | 119°55' | June 28, 1984 | " " | " " |
| | 6 | Wells Gray | 51°48' | 120°00' | June 29, 1984 | " " | " " |
| Western Hemlock | 7 | Jordan River | 48°26'30" | 124°02'00" | June 21, 1983 | Northern Pacific Coast | Coastal western hemlock |
| | 8 | Port McNeill | 50°30'20" | 127°08'30" | June 24, 1983 | Southern Pacific Coast | " " " |
| Lodgepole Pine | 9 | Wells Gray | 51°48' | 120°00' | Oct. , 1983 | Central Douglas-fir | Interior Douglas-fir |
| | 10 | Jacobie Creek | 52°33'30" | 121°48'30" | Aug. 4, 1983 | " " | Cariboo aspen, lpp, D-f |
| Interior Spruce | 11 | Wells Gray | 51°48' | 120°00' | Oct. 18, 1983 | " " | Interior Douglas-fir |
| | 12 | Claude Lake | 52°34' | 122°07'30" | Oct. 19, 1983 | " " | Cariboo aspen, lpp, D-f |
| Western Red Cedar | 13 | Horne Lake | 49°19'25" | 124°41'30" | May 8, 1984 | Straight of Georgia | Coastal Douglas-fir |
| | 14 | Shawnigan R* | 48°47' | 123°50' | May 9, 1984 | " " | " " |

* Released site
** Interior sites are in the Montane Forest Region and Coastal sites are in the Coast Forest Region, according to Rowe's classification (1972).

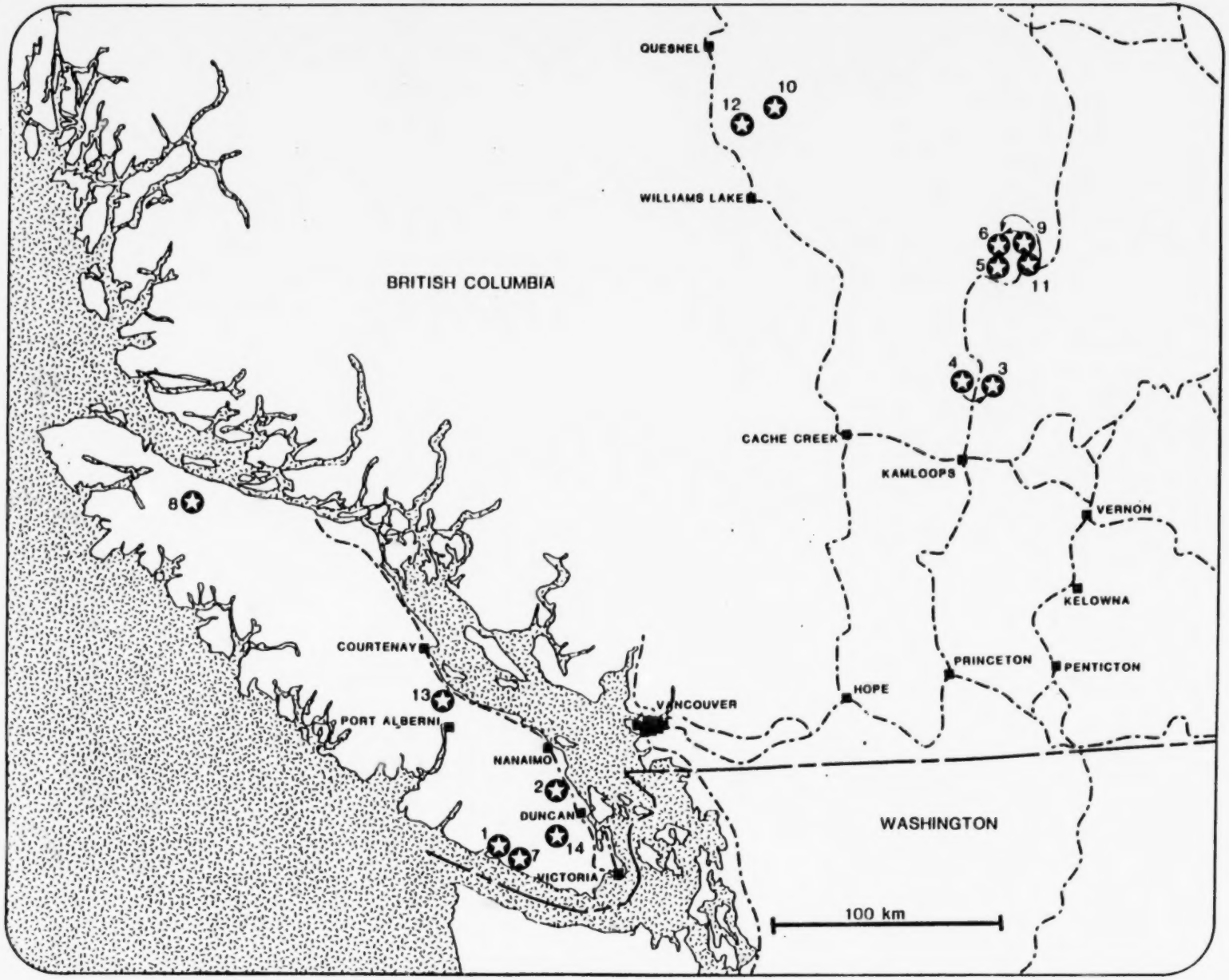


Figure 1 Map of Sampling Sites

which involved taking exploratory increment cores at breast height (BH, at 1.3 m above ground). With the exception of Jordan River, sampling sites were naturally regenerated and had received no silviculture treatment. The Jordan River Douglas-fir and western hemlock mixed stand (80:20 percent) was treated in 1973 by thinning approximately 25 percent of the stand volume.

Five trees were sampled at each site. A total of five cross-sectional discs, 7 - 15 cm thick, were cut from each tree; one at BH and four others at one-fifth intervals of total height.

Intensive sampling (five sections per tree) was undertaken in order to provide information about ring width, ring density, yearly average height increment and taper along the bole for detailed stem analysis. In addition to these physical characteristics, the longitudinal shrinkage at BH and certain chemical characteristics, such as extractives content (water and alcohol-benzene), lignin and holocellulose contents, were examined at various positions in the stem-wood. These results are reported in other reports.

Individual trees selected for sampling were dominant or codominant in their growth habit. A spatial separation of at least 50 m between sample trees ensured that the trees sampled were of different lineage.

## 4.2 SAMPLE PREPARATION

Three hundred and fifty cross-sectional discs (14 sites, five trees, and five sampling positions) were sub-sampled in the laboratory carpenter shop for X-ray densitometric evaluation. Two radial strips, about five mm thick and six mm wide (resembling increment cores), were cut from each disc, from pith to bark, for X-ray densitometry. The radial increment strips were obtained from two average radii (at least 90 degrees apart), avoiding compression wood, knots, resin pockets or other aberrations.

## 4.3 X-RAY DENSITOMETRY

Ring-width and ring-density data were derived for this study by using X-ray densitometry. X-ray densitometry techniques and instruments used at Forintek are described in detail elsewhere (Parker *et al.*, 1980). The following is a brief description of the techniques involved:

1. increment cores are air-dried, then glued between two mounting sticks;

2. mounted cores are cut to uniform thickness on a twin-blade saw designed for this purpose;

3. samples are labeled with X-ray opaque paint;

4. a portion of one core mounting stick is cut away and the cell angle (the angle formed by the long axis of longitudinal tracheid cells and the long axis of the increment core) is measured under a microscope;

5. prepared cores are placed on X-ray film with calibration wedges, then exposed at the proper angle by a moving X-ray machine;

6. X-ray film is carefully developed;

7. the radiograph is examined on a light table under a low-power microscope, and calendar-year dates and other information are marked on it;

8. radiographs are scanned on a computerized densitometer that converts increment core images into ring-width and ring-density data; and

9. data are stored on magnetic tapes for further processing and summarizing.

## 4.4 TREE RING DATA

Two basic forms of data were measured by the computerized densitometer:

1. distance, which represents the ring-width components in 0.01 mm increments;

2. density*, which represents the intra-ring density profiles with 0.05 mm resolution.

Forintek's data acquisition Tree Ring Input Program (TRIP) was used to obtain the following eight tree-ring variables: ring width (RW), earlywood width (EW), latewood width (LW), ring density (RD), earlywood density (ED), latewood density (LD), minimum ring density (MND), and maximum ring density (MXD).

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*All density values were expressed on an ovendry volume and weight basis. The quoted numbers are, therefore, about 10 percent higher at the 0.45 level than the conventional basic wood density, which is always expressed on a green volume and ovendry weight basis.

## 4.5 ASSESSMENT OF ENTIRE STEM-WOOD DENSITY TRENDS AND PRESENTATION OF DATA

Reconstructing past growth and development of a tree by measuring annual rings from pith to bark at a number of points along the bole, i.e., a complete stem analysis, has many applications in forestry. Forintek's stem analysis technique is especially informative because, in addition to ring width, it includes wood density measurements. Density values are available as yearly averages, earlywood, latewood, minimum, maximum (and 100 intra-ring density profile points, regardless of ring width).

Systematic variations in stem-wood density may be assessed in a variety of ways. The problem of what classification scheme to follow in complete stem analysis was solved by classifying and plotting ring density features along three different gradients as described by Duff and Nolan (1953), and Fritts (1976). Figure 2 graphically illustrates the three classification schemes for a seven-year-old tree. The large triangle in this illustration represents one half of the longitudinal section of the bole, from pith to bark, and from the base to the tip (exaggerated horizontal scale was used for illustrative purposes). Note that each annual growth layer corresponds to a trapezoid in the figure (with the exception of the first one which is a triangle). The symbols resembling "fleur-de-lis" represent the position of the terminal bud (on top of the leader) at the end of each of the seven growing seasons. The three classification schemes described by Duff and Nolan (1953) are shown by the horizontal (1), diagonal (2), and vertical (3) arrows.

The first classification gradient (1) represents the usual horizontally arranged sequence of rings which is affected by climatic variation and the increase in tree age. Yearly average densities for whole rings were summarized for the five intensively sampled trees and these data were plotted for all five sampling heights for each site.

The second classification scheme (2) represents the diagonal series of rings at various stem heights for the same calendar year and expresses changes associated with increasing stem height and decreasing cambial age. When different aged stands are being compared by this technique, the graphical presentation of tree-ring data has the curves "right justified"; the cutting dates are the common points of reference. As a practical example, this second type of classification scheme would best describe the density variation in a long piece of structural lumber with wane.

The third classification scheme (3) represents a vertically arranged sequence, with each ring sampled at a given cambial age. In other words, the summaries are made by age. In plotting different aged stands, the pith-year (or year one) would be the common point of reference; the curves would be "left justified." This third classification scheme would best describe the density trends in a piece of structural lumber with the pith "boxed in."

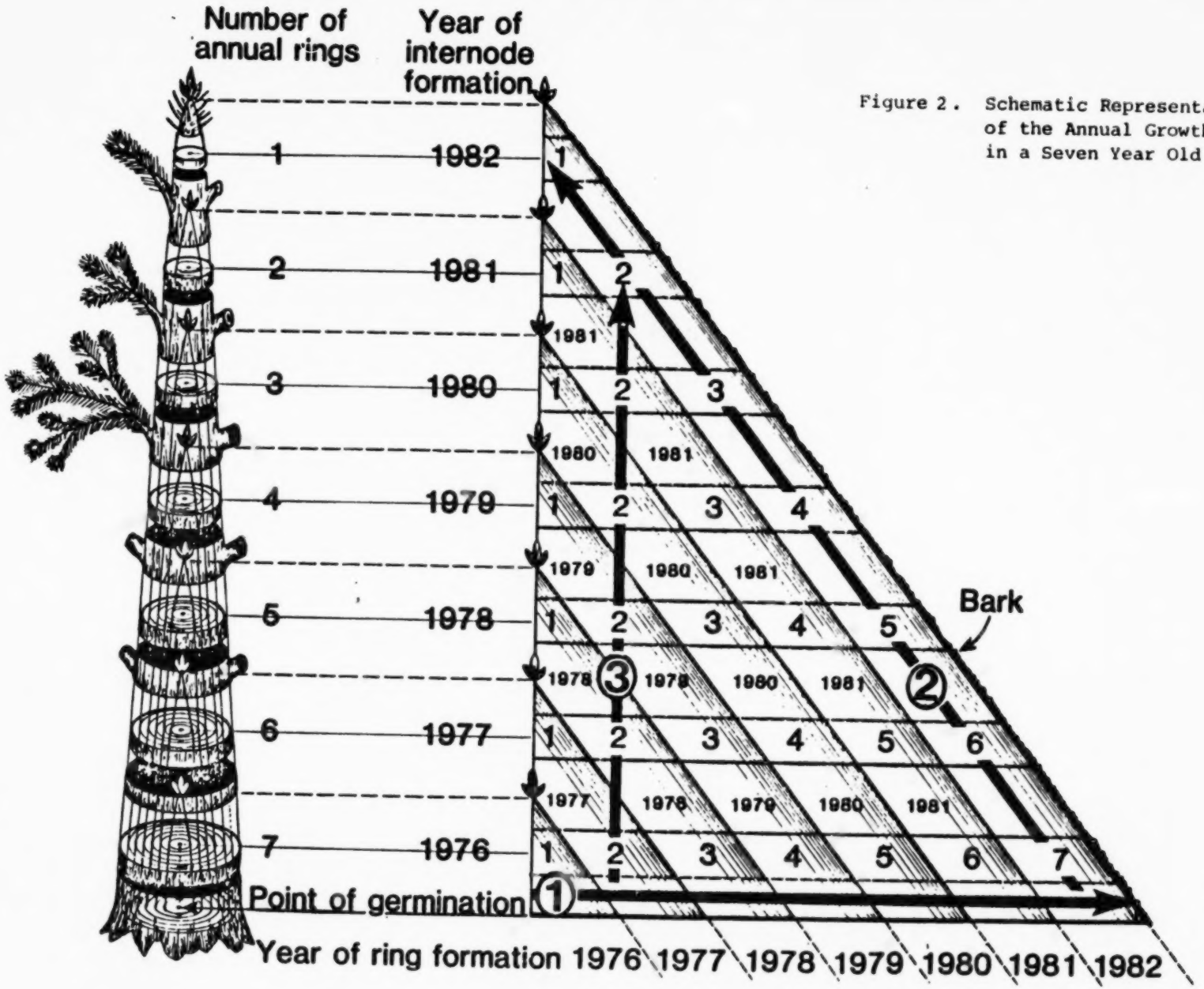



Figure 2. Schematic Representation of the Annual Growth Layers in a Seven Year Old Tree.

Some workers have proposed that the third classification scheme (vertical summary by age) is best suited for studying the influences of site quality (Timmer and Verch, 1983). However, in this report all three classification schemes were utilized for examining the density distribution and variation in the stem-wood.

Figure 3 shows the different means of average ring density comparisons used in this study: (a) "horizontal" pith-to-bark average ring density trends at different sampling heights; (b) the diagonal means of density summary expressed as a function of age and on a stem volume basis, and; (c) average density of the entire disc sample at the five sampling heights (vertical comparison).

Three arbitrary density zones were delineated and mapped in the stem-wood for two Coastal and two Interior Douglas-fir sites. The first zone represented relatively low density wood, the second zone encompassed an average density range for the site being described, and the third zone delineated the relatively high density wood.

### 4.6 RECONSTRUCTION OF YEARLY ENTIRE ANNUAL RING WEIGHTS IN THE STEM-WOOD FROM PITH-TO-BARK (YEARW)

The weight of entire annual increments in the stem-wood was obtained by processing the TRIP data for each tree. Annual rings were summarized by calendar years; i.e., keeping the year of annual ring formation constant (Duff and Nolan, 1953). The weight of an entire annual increment in the stem-wood depended on:

1. its radial distance from the pith at breast height,
2. its ring width along the stem (taper),
3. its average ring density, and
4. its distance up the stem to the tip of the leader for that year's growth.

Stem-wood biomass productivity was calculated and plotted on an annual basis for each of the five trees for each sampling site.

## 5.0 RESULTS AND DISCUSSION

The yearly ring density data have been integrated by means of a stem analysis approach to determine the change in the average density of the entire stem-wood as a function of increasing age and total stem volume. Finally, combining the entire yearly stem volumes with average densities, the yearly entire annual ring weights in the stem-wood were plotted from pith-to-bark. Because of the sheer magnitude of the data base, its complexity, its species-to-species,

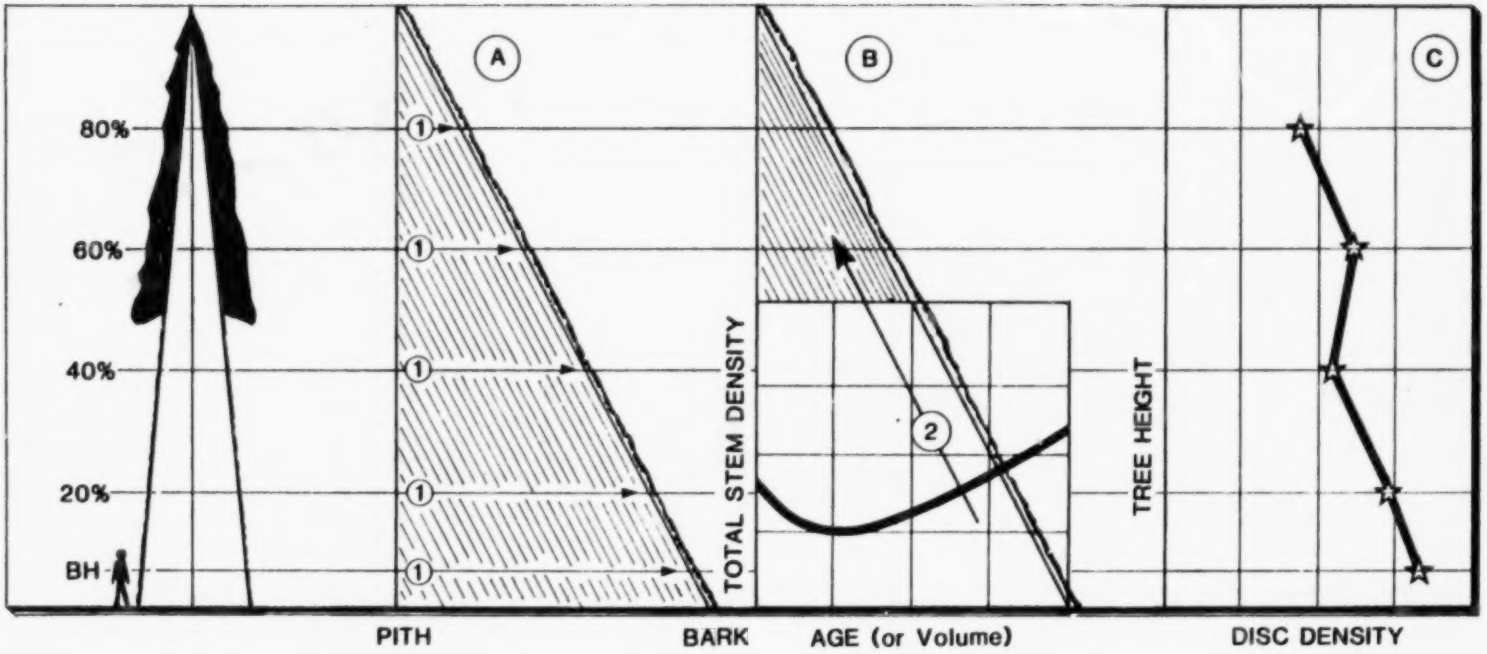



Figure 3 Different Means of Average Ring Density Comparisons

site-to-site, and tree-to-tree differences, only the Jordan River Douglas-fir site will be discussed in detail. Other sites and species will be dealt with in general, synoptic terms.

## 5.1 JORDAN RIVER DOUGLAS-FIR

Pith-to-bark yearly average ring density trends are shown in Figure 4a for five height positions, for a typical Douglas-fir sample tree for the Jordan River site. These are yearly ring density data for two scan lines, shown as broken line plots. Also shown is the smoothed average trend line (dashed line).

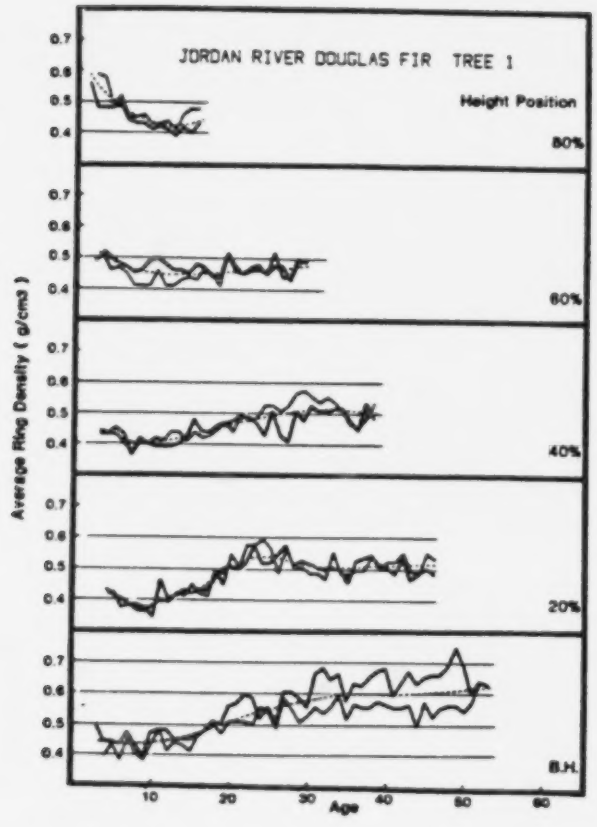
At BH the general trend in yearly average ring density, including all five sample trees, is a declining one from the pith to about age eight; from about 0.47 to 0.43 g/cm$^3$ (Figure 4b). The average density of the BH discs is about 0.52 g/cm$^3$, therefore this decline is about eight percent. From age 10 to 30 a relatively rapid increase is evident at BH, from 0.43 to 0.54 g/cm$^3$, or about a 29 percent increase (again, the basis of comparison, or 100 percent, is the Jordan River site average at BH 0.52 g/cm$^3$). From age 30 to age 53 (time of sampling) average ring density levels off or increases slightly (only about five percent) for the Jordan River Douglas-fir sample trees' BH discs.

At the 20 percent sampling height with 46 annual rings, a similar RD pattern was observed; initial decline, then rapid increase followed by levelling off or only a slight increase. The overall average RD of the five sample trees was 0.50 g/cm$^3$ at this height; about a four percent decline from BH.

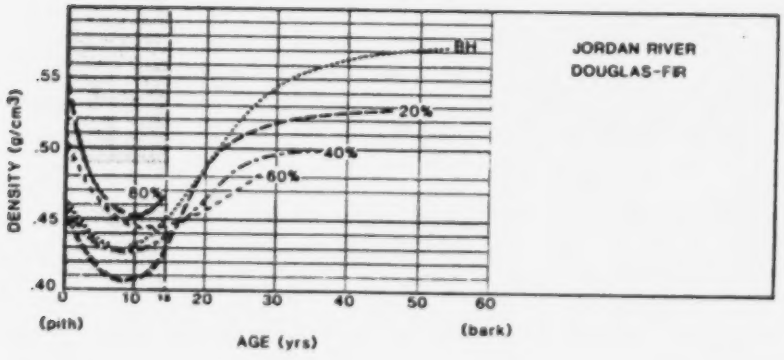
The 40 percent height position disc samples also showed a pith-to-bark ring density increase; on the average from 0.43 to 0.50 g/cm$^3$. The overall average density of the five sample trees at this height was about 0.46 g/cm$^3$; about an 11 percent decline from BH. The five sample trees had 37 annual rings at this height, on the average.

At the 60 percent sampling position a density decline was noted from the pith to about the 10th annual ring, which was followed by an increasing density trend from age 15 to 28. The average density of the five discs at this sampling height was about 0.47 g/cm$^3$; approximately nine percent lower than the BH disc density.

The 80 percent sampling height discs were only about 15 years of age, showing a pith-to-bark density decline. This is not unlike the innermost 15 years of growth at the other sampling heights (BH, 20, 40, and 60 percent). The average disc density here was about 15 percent lower than the BH average. In fact, this innermost 15 years of growth in the Jordan River Douglas-fir sample trees is almost uniformly low-density wood, with the exception of the 60 and 80 percent heights where the first two to three rings contained relatively more dense wood (Figure 4b). The average density distribution of this "stove-pipe-like" inner cylinder, from the base to the top is as follows: 0.44, 0.42, 0.43, 0.45, and 0.46 g/cm$^3$,




a




b

Figure 4 Pith-to-Bark Average Ring Density at the Five Height Positions in the Stem-Wood for Jordan River Douglas-fir; Two Scan-Lines and Smoothed Trends are Shown for Tree No. 1(a) and Site-average Smoothed Trend-Lines Based on Five Sample Trees (b)

corresponding to the BH, 20, 40, 60, and 80 percent height positions. This inner cylinder of low density wood has an average density of 0.44 g/cm$^3$.

Figure 5a illustrates the relative distribution of low, average and high density wood in the stem from the base to the top and from pith to bark. Average disc density values for the five trees from this site are also plotted in Figure 5b for the five sampling heights. It can be seen that average disc density declines from BH through 20, 40, 60, and 80 percent sampling heights; 0.52, 0.50, 0.46, 0.47, and 0.44 g/cm$^3$, respectively.

Tree height and the base of live crown were drawn to scale in Figure 5a but stem-wood taper was not. In fact, the horizontal scale was exaggerated to permit the mapping of density distribution. It is interesting to note that the more dense ($>$0.49 g/cm$^3$) mature wood extends from the stem base to the base of the live crown. If there were a biological connection, and there is no reason to believe that there is not, this would suggest that the tree has produced and will produce mature wood always below the live crown. The practical implications of this observation could be useful in pruning prescriptions for this type of Douglas-fir stand.

It must be pointed out at this juncture that these trends are not so much species (Douglas-fir) related as site related, as will be shown later with other Douglas-fir site descriptions. Also, and equally importantly, it must be noted that a five-tree sample population cannot describe adequately the total population of a sampling site. These initial results simply suggest certain density trends (e.g., declining trend from the base to the top of the stem-wood), density distributions and low-to-high density ranges.

Total stem-wood density trends were also plotted by increasing age at BH and by total stem-wood volume (m$^3$), and are shown in Figures 6a and 6b. These summaries were made by the second density classification gradient, i.e., diagonally.

In Figure 6a, two notable features can be observed: first, the range or the difference between the low (tree No.4) and high (tree No.3) density sample trees; second, the rate of change (the slope of the curves) in density from inner juvenile wood to outer mature wood. At about age 53 the density range between trees 4 and 3 (low and high density) is approximately 20 percent - 0.44 to 0.54 g/cm$^3$. Interestingly, the relative "ranking" is very stable from age 15 to 53. Because density is an inherited trait, this initial result suggests a good potential for selecting and growing high density wood at this site. The following average stem-wood densities were found at 10, 20, 30, 40, and 50 years of age: 0.40, 0.43, 0.45, 0.47, and 0.49 g/cm$^3$, respectively.

Figure 6b shows that these five sample trees had reached an average volume of 3.7 m$^3$ and ranged from 2.7 m$^3$ (for tree No.5) to 5.5 m$^3$ (tree No.2). This figure further shows that the 0.43 average density attained at age 20 (Figure 6a) amounts to 0.57 m$^3$ stem

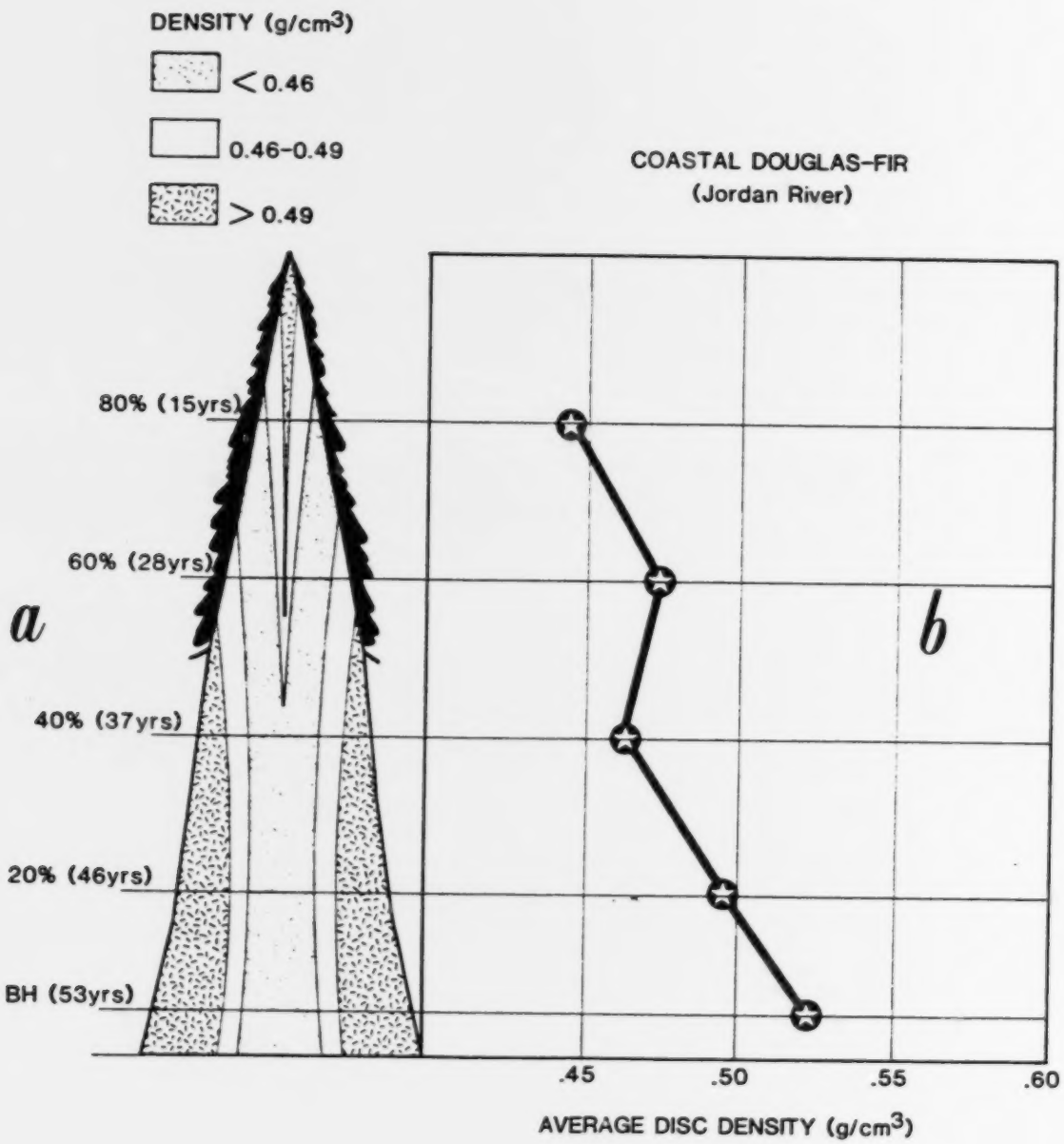



Figure 5 Density Distribution in the Stem-Wood for Jordan River Douglas-fir Showing Comparatively Low, Average and High Density Wood (a) and Average Disc Densities (b)

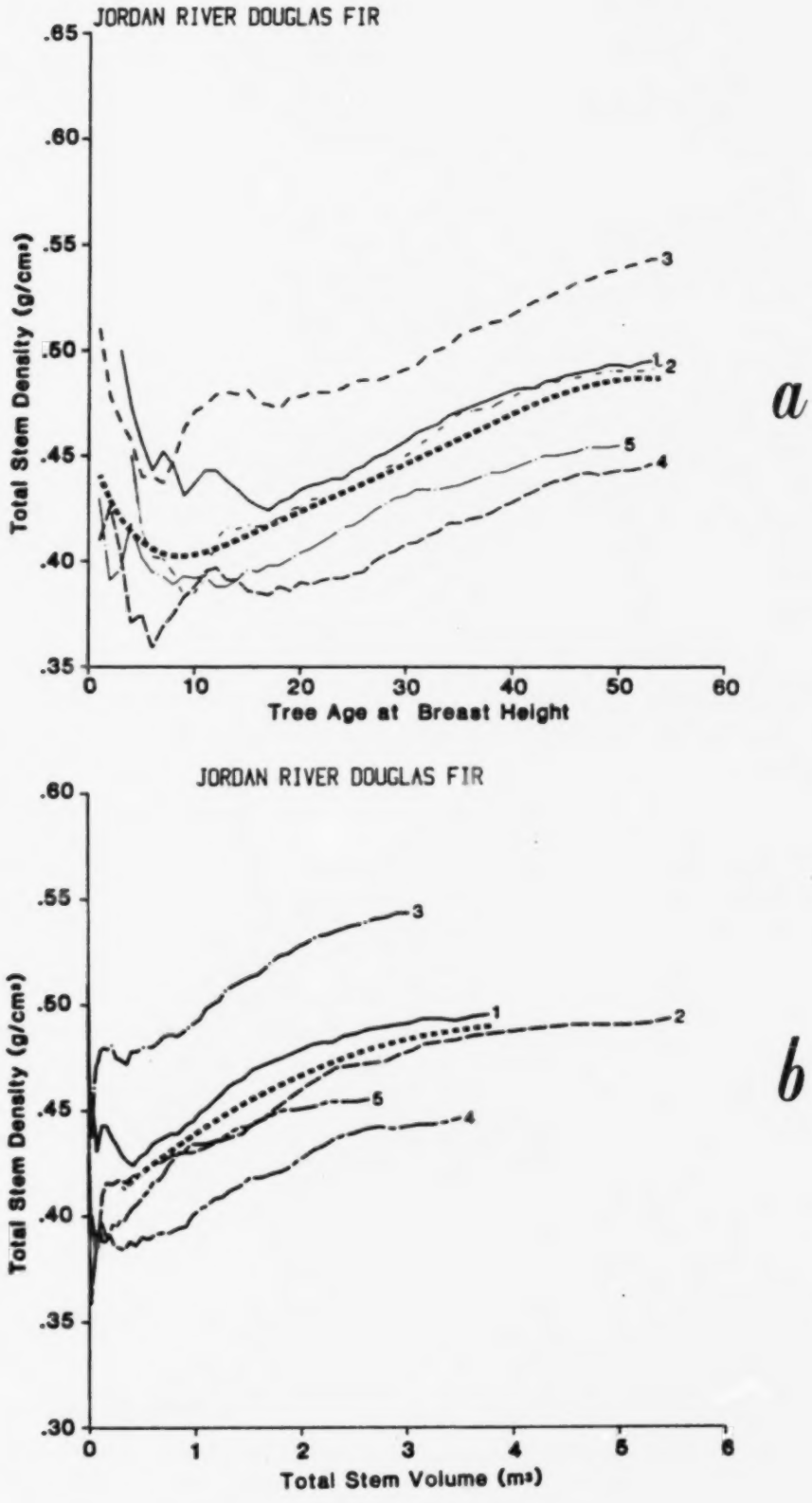



Figure 6 Total Stem-Wood Density by Age at BH (a) and by Total Stem Volume (b) for the Jordan River Douglas-Fir Site

volume, or about 15 percent of the total volume at age 53. However, the total stem density at this volume was expressed through the second classification gradient (diagonally); therefore, this volume (0.57 $m^3$) encompasses only the cone-shaped bottom part of the inner juvenile-wood cylinder depicted in Figure 5a. This example illustrates both the validity and the necessity of all three density classification gradients. It is recommended that the third density classification system (vertical summary by age) be developed for the Jordan River Douglas-fir trees to quantify the low density inner juvenile wood, which was shown in Figure 5a, extending from the base to the top of the stem-wood (Timmer and Verch, 1983, suggested that this system is the one best suited for studying site quality).

Total stem-wood density development is shown as a function of tree age at BH in Figure 6a. In Figure 6b the same density mile-posts (reached at age 20, 30, 40, and 50) were contained in the following total stem volumes:

| Age at BH (years) | Total Stem Density ($g/cm^3$) | Total Stem Volume ($m^3$) |
|---|---|---|
| 20 | 0.43 | 0.57 |
| 30 | 0.45 | 1.12 |
| 40 | 0.47 | 2.10 |
| 50 | 0.48 | 3.17 |

Total stem-wood density trends were plotted by increasing age at BH and by total stem-wood volume for the other Douglas-fir sites and for the other species (western hemlock, lodgepole pine, Interior spruce and western red cedar) and are shown in Appendix I.

Yearly entire annual ring weight (YEARW) productivity rates are presented for the five Douglas-fir sample trees from Jordan River in Figure 7. A high degree of variability is evident year-to-year within individual trees and also between the five trees. A cross-dating signal is also present between the trees and is thought to be climate (precipitation and temperature) related (Jozsa et al., 1985). This cross-dating signal is shown by the coincidental peaks (such as in 1977, 1954, and 1949) and troughs (such as in 1969 and 1951).

Figure 7 shows a very dynamic and productive site; there is no sign of declining productivity for these trees. The last complete annual ring, dating to 1982 and covering the entire stem-wood, weighed about 71 kg (O.D.). In order to create a broader perspective for this 71 kg entire annual ring weight value, other sites and other species will be compared with Jordan River in subsequent sections of this report.

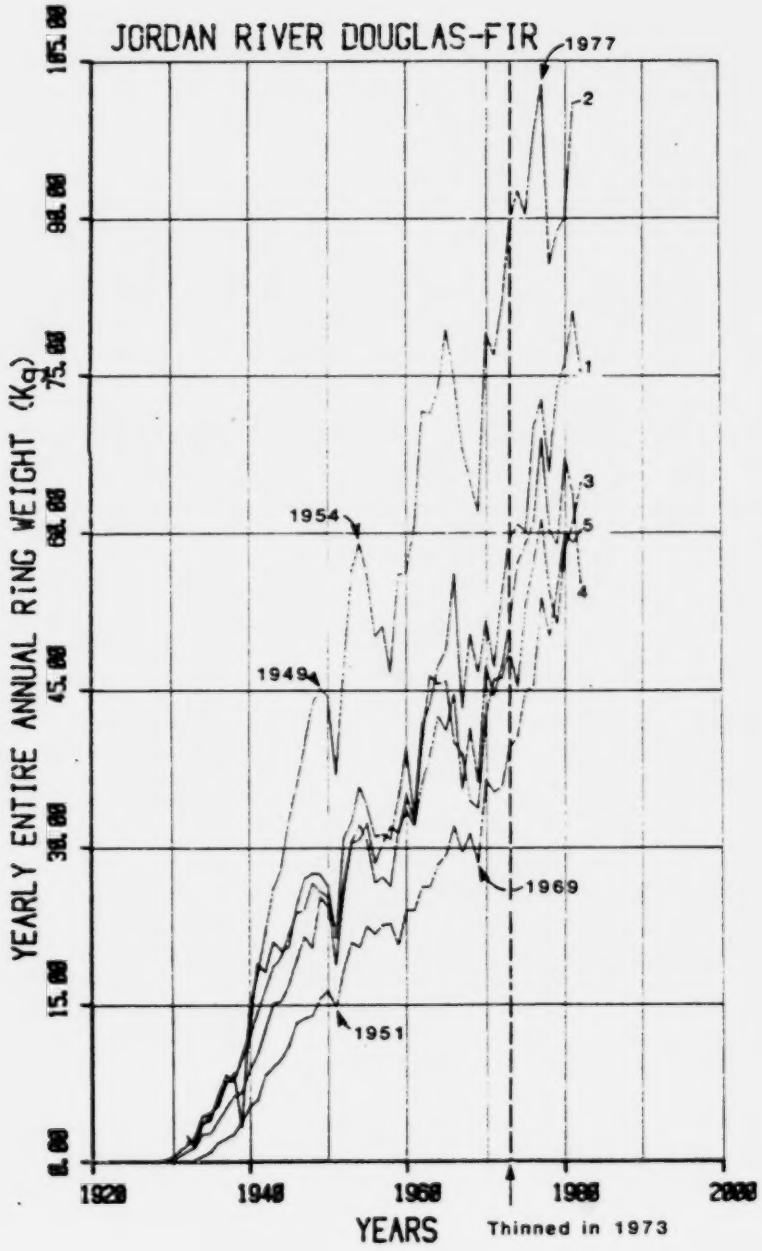



Figure 7 YEARW Productivity Rates of Five Douglas-Fir Sample Trees from Jordan River

## 5.2 AVERAGE DENSITIES AT FIVE SAMPLING HEIGHTS FOR FIVE SPECIES

Table 2 and Figure 8 show the average density values for each of the five sampling heights, five species and 14 sites. These data were plotted to examine site-to-site differences within single species (e.g., six sites for Douglas-fir). In addition, between-species comparisons can be made quite readily through this type of data representation. For example, the top half of the stem-wood for western red cedar and Interior spruce show identical density levels and patterns (Figure 8a). Western red cedar shows a steady increase in average density from about 0.30 g/cm$^3$ at BH to about 0.39 g/cm$^3$ at 80 percent stem height. Interior spruce, on the other hand, shows a stable density from BH through 20, 40, and 60 percent heights; then density increases from 0.34 to about 0.38 at the 80 percent height.

Lodgepole pine stem-wood shows the least variation in density as a function of height. Stem-wood average density is about 0.42 g/cm$^3$ from the BH to the 80 percent height.

Figure 8a also illustrates the average density trends of three Douglas-fir sites: a Coastal site (Copper Canyon) and two released sites from the Interior (Heffley and Galena). The Copper Canyon Coastal site shows a declining density trend from the base to the top of the stem-wood; from 0.57 to 0.46 g/cm$^3$ (a 19 percent drop, using the BH datum as the basis of reference). The Heffley and Galena released sites also show a declining trend, but only from the BH to the mid-point of the stem-wood; 0.53 to 0.47 g/cm$^3$ (approximately 11 percent drop). From 40 to 80 percent height density increases slightly from 0.47 to 0.48.

Western hemlock average disc densities decreased from BH to 40 percent height and then increased to the 80 percent tree height (Figure 8b). The decrease was about 10 percent from 0.44 to 0.40 g/cm$^3$ and the increase was slightly more; 11 percent. Figure 8b illustrates the declining density trend for the Jordan River Douglas-fir; from 0.52 to 0.44 (a 15 percent drop from BH to 80 percent height). The Interior wet-belt Douglas-fir site, Wells Gray, shows about an eight percent decline in density from BH to 20 percent height; then a steady increase from 0.41 to 0.47 g/cm$^3$, about 14 percent from 20 to 80 percent height.

The dry-belt Interior Douglas-fir site at Heffley shows almost an identical pattern to that of the Coastal site at Jordan River. Density decreases from BH to the 40 percent height (0.52 to 0.44 g/cm$^3$), then increases (unlike at Jordan River) from this point to the 80 percent height (0.44 to 0.47 g/cm$^3$) as shown in Figure 8b.

As a means of summarizing the above density trends, from BH to 80 percent height, species average trends are shown in Figure 9. Not surprisingly, western red cedar is the least dense species (two sites from Vancouver Island had an overall average stem-wood density of 0.33 g/cm$^3$); followed by the Interior spruce which had no variation

Table 2

Average Density Values for the Five Sampling Heights for each Site and Species

| Sampling Height (Percent) | Douglas-Fir | | | | | | W. Hemlock | | Lodgepole P. | | I.Spruce | | W.r.Cedar | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jordan River | Copper Canyon | Heffley | Heffley Released* | Galena Released* | Wells Gray | Jordan River | Port McNeill | Wells Gray | Jacobie Creek | Wells Gray | Claude Lake | Horne Lake | Shawnigan R. |
| 80 | 0.44 | 0.46 | 0.47 | 0.49 | 0.48 | 0.47 | 0.44 | 0.48 | 0.42 | 0.42 | 0.37 | 0.40 | 0.40 | 0.38 |
| 60 | 0.47 | 0.50 | 0.46 | 0.48 | 0.46 | 0.45 | 0.42 | 0.43 | 0.42 | 0.42 | 0.34 | 0.35 | 0.35 | 0.34 |
| 40 | 0.46 | 0.48 | 0.44 | 0.47 | 0.47 | 0.44 | 0.41 | 0.38 | 0.44 | 0.41 | 0.33 | 0.35 | 0.35 | 0.33 |
| 20 | 0.50 | 0.51 | 0.48 | 0.50 | 0.49 | 0.41 | 0.42 | 0.39 | 0.43 | 0.41 | 0.33 | 0.35 | 0.32 | 0.30 |
| BH | 0.52 | 0.57 | 0.52 | 0.53 | 0.53 | 0.44 | 0.46 | 0.43 | 0.43 | 0.43 | 0.33 | 0.36 | 0.30 | 0.29 |
| Site average Total Stem-wood Density | 0.49 | 0.53 | 0.47 | 0.49 | 0.48 | 0.43 | 0.43 | 0.42 | 0.44 | 0.42 | 0.35 | 0.36 | 0.34 | 0.33 |

* Density values are shown for the periods of growth after release

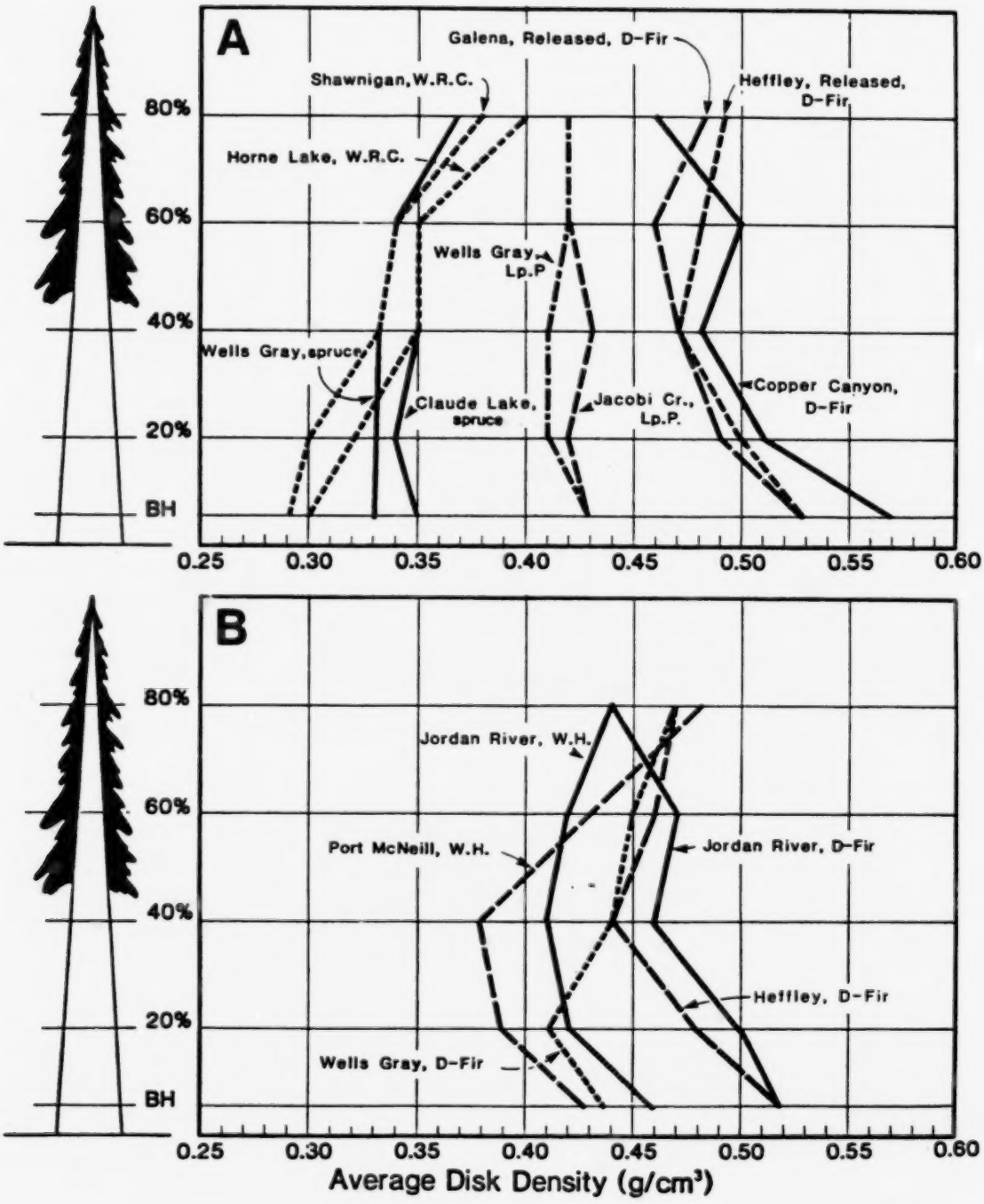



Figure 8 Average Disc Densities at Five Sampling Heights for Five Species and 14 Sites

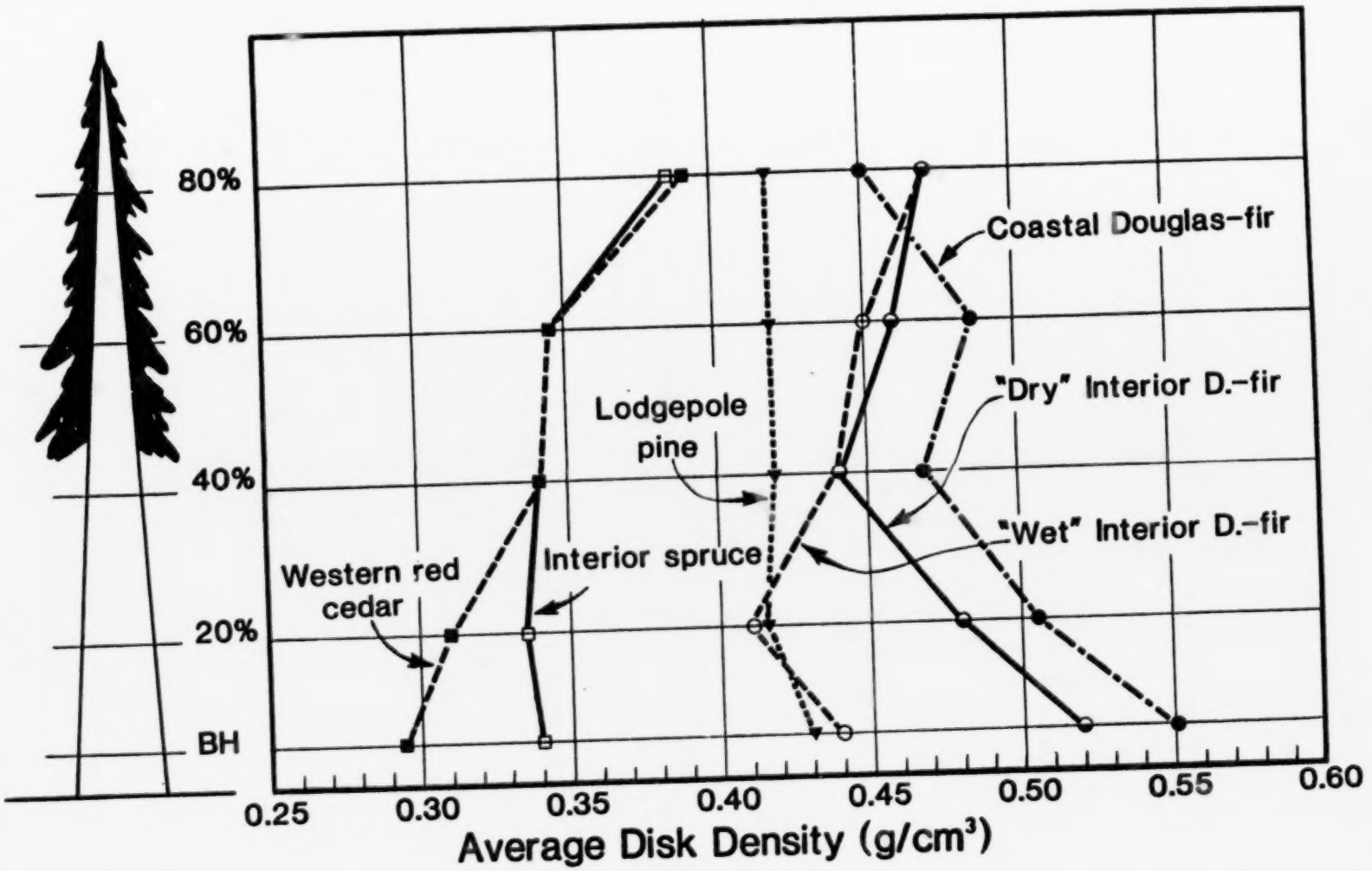



Figure 9 Average disc density trends from BH to 80 Percent Height for Different Species and Sites

in average stem-wood density from BH to 60 percent height. Lodgepole pine, with an average stem-wood density of about 0.42 g/cm$^3$, shows remarkable stability in average stem-wood density from the base to the top.

Somewhat surprisingly, the Coastal Douglas-fir sites produced, on the average, denser wood than the Interior sites; overall average of 0.51 compared with 0.47 g/cm$^3$, respectively. The Interior wet-belt site (at Wells Gray) was the least dense Douglas-fir in this study, at 0.43 g/cm$^3$ total stem-wood density (which is on par with typical western hemlock density values, as shown in Table 2).

## 5.3 PITH-TO-BARK DENSITY TRENDS IN THE STEM-WOOD

Pith-to-bark average yearly ring density trends were described in detail for the Jordan River Douglas-fir site at all five sampling heights. It was shown that the BH disc's ring-density trend-line gave a good approximation of the juvenile wood (the first 15 years of growth) in the stem-wood. Therefore, a synopsis was prepared of the yearly average density trends at breast height, from pith-to-bark, for the five species at 14 sampling sites (Figure 10). These trend lines in Figure 10 were derived by averaging the density trends at breast height for the five sample trees at each site.

As expected, the low-high density limits are bracketed by western red cedar (0.30 g/cm$^3$) and Douglas-fir (0.60 g/cm$^3$). For Interior spruce and western red cedar the first 10-15 years of growth produced relatively high density wood. From about 15 years of age the Interior spruce average density trend is very stable or slightly increasing, whereas for western red cedar a slight decrease is evident.

Western hemlock from Jordan River and Port McNeill also has relatively high density core-wood for the first 10 years of growth. Low density wood is evident for both sites from age 10 to 20 (Figure 10). A rapid increase in density is shown from age 20 to about age 40.

Lodgepole pine from the B.C. Interior has a relatively stable density trend from pith-to-bark for both sites; Jacobie Creek and Wells Gray.

Of the six Douglas-fir sites (Jordan River, Copper Canyon, Heffley Released, Heffley, Galena Released, and Wells Gray) only three had shown comparatively low-density core-wood (compared to the mature outerwood); Copper Canyon, Jordan River, and Heffley (Figure 11). Interestingly, two of these are Coastal sites. It appears that the Interior Douglas-fir sites do not have relatively low density juvenile core-wood when compared with the Coastal sites. Although the Interior equivalent of the Coastal sites, Wells Gray from the Interior wet belt, had shown no sign of low density core-wood; its outer mature wood is the least dense of all six sites, Figure 11.

The average density of the innermost 15 years of growth (core-wood or juvenile wood) was determined for the six Douglas-fir sites at each of the five sampling heights. The results are shown in Table 3. In

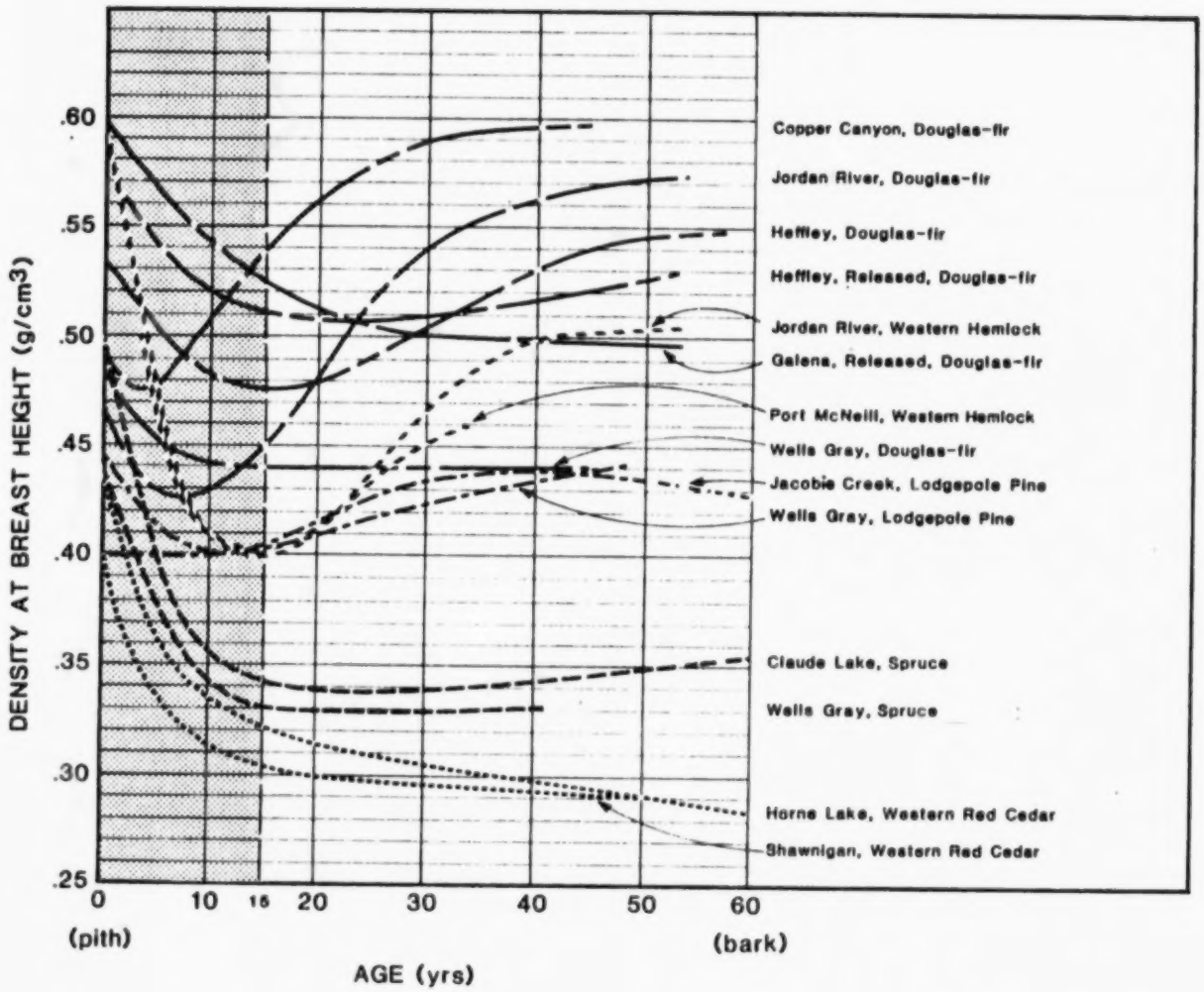



Figure 10 Average Annual Ring Density Trends at BH from Pith-to-Bark for Five Species and 14 Sampling Sites

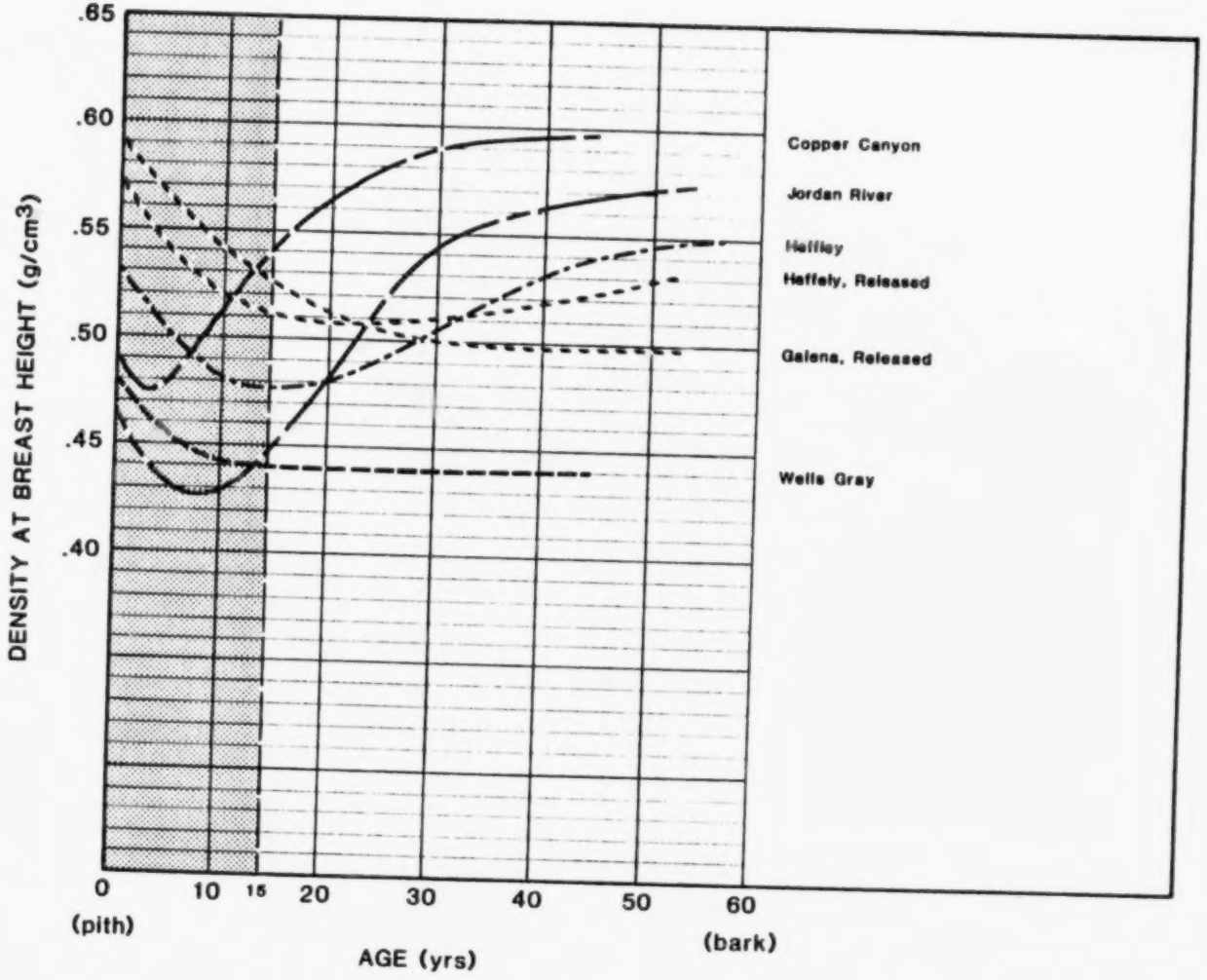



Figure 11 Average Annual Ring Density Trends at BH from Pith-to-Bark for the Six Douglas-Fir Sites

spite of the relatively wide density range of the total stem-wood (0.43 to 0.53 g/cm$^3$) a high degree of uniformity is evident in the entire core-wood from BH to 80 percent height. Site averages range from a low of 0.44 (Jordan River and Wells Gray) to a high of 0.48 g/cm$^3$ (Copper Canyon, Heffley Released, and Galena Released). The difference between total stem-wood and the entire "stove-pipe" like inner core-wood was determined to assess the relative impact of density non-uniformity (Table 3). The Coastal sites, Jordan River and Copper Canyon, both had a density difference of 0.05 g/cm$^3$; 10.2 and 9.4 percent, respectively. The Interior sites varied from a high of 0.01 to a low of -0.01 g/cm$^3$ (2.1 to -2.3 percent), or about one-fifth of the Coastal figures.

In order to assess the pith-to-bark yearly trends, and transition from "juvenile" to "mature" wood at the five sampling heights, two Coastal and two Interior Douglas-fir sites were examined in greater detail. The five sample trees' data were averaged for each site and the results are shown in Figures 12 and 13. Pith-to-bark yearly average ring density trend-lines were plotted for the other species also and are shown in Appendix II.

Jordan River Douglas-fir (Figure 12a) with a site average stem-wood density of 0.49 g/cm$^3$, marked by the big horizontal arrow, had about 10 percent less dense core-wood (0.44 g/cm$^3$, marked by small arrow). Twenty percent height position had the least dense and 80 percent had the most dense core-wood. At this site each disc, at each sampling height, had some wood less dense than 0.46 g/cm$^3$ which was produced between about age two and 17 at BH (Figure 12a); pith to age 17 at 20 percent; pith to age 20 at 40 percent; age 5 to 22 at 60 percent; and age 6 to 13 at the 80 percent sampling height. Dense wood (above 0.49 g/cm$^3$) was produced mainly in the lower half of the stem-wood (at BH, 20 and 40 height) from age 21 at BH and 20 percent height and from age 26 at the 40 percent sampling height. Small amounts of dense wood were laid down in the first two to three years at 60 and 80 percent height.

At the Copper Canyon site the average stem-wood was 0.53 g/cm$^3$ (the highest average of all 14 sites). The innermost 15 annual rings at all five sampling heights had an average density of 0.48 g/cm$^3$; about 9.4 percent below the total stem-wood (marked by small arrow in Figure 12b). At this site the 40 percent height sample disc had the lowest density core-wood (0.45 g/cm$^3$). More dense wood (above 0.49 g/cm$^3$) was produced at an earlier age at BH than at Jordan River; age seven compared with age 21 (Figure 12). At 20 and 40 percent height the more dense wood was produced from about the 13th and 19th annual rings from the pith, respectively. Wood less dense than 0.46 g/cm$^3$ was quite limited in its distribution in the stem-wood, as shown in Figure 12b. Furthermore, the average density of the innermost 15 years of core-wood at this site (0.48 g/cm$^3$) equals or surpasses total stem-wood values of other Douglas-fir sites (Table 3).

Figure 13 shows the average annual ring density trends at five sampling heights for a dry Interior (Heffley) and a wet Interior (Wells Gray) Douglas-fir site. At Heffley the ring density trend lines indicate that the first 15 years of growth at each sampling

Table 3

Average Density of the First 15 Years of Core-Wood at Five Sampling Heights for the Six Douglas-Fir Sites

| Sampling Height (Percent) | Jordan River | Copper Canyon | Heffley Creek | Heffley Released | Galena R Released | Wells Gray | Douglas-fir Average for All Six Sites |
|---|---|---|---|---|---|---|---|
| 80 | 0.46 | 0.48 | 0.48 | 0.51 | 0.49 | 0.47 | 0.48 |
| 60 | 0.45 | 0.48 | 0.45 | 0.49 | 0.50 | 0.45 | 0.47 |
| 40 | 0.43 | 0.45 | 0.44 | 0.45 | 0.45 | 0.44 | 0.44 |
| 20 | 0.42 | 0.48 | 0.45 | 0.46 | 0.45 | 0.41 | 0.45 |
| BH | 0.44 | 0.50 | 0.49 | 0.48 | 0.49 | 0.45 | 0.47 |
| Average Density of the first 15 Annual Rings from the Pith | 0.44 | 0.48 | 0.46 | 0.48 | 0.48 | 0.44 | 0.46 |
| Total Stem-Wood Density ($g/cm^3$) | 0.49 | 0.53 | 0.47 | 0.49 | 0.48 | 0.43 | 0.49 |
| Total Stem-Wood Minus Entire Core-Wood at Age 15 | 0.05 | 0.05 | 0.01 | 0.01 | 0.00 | -0.01 | 0.030 |
| Percent | 10.2% | 9.4% | 2.1% | 2.0% | 0.0% | -2.3% | 6% |

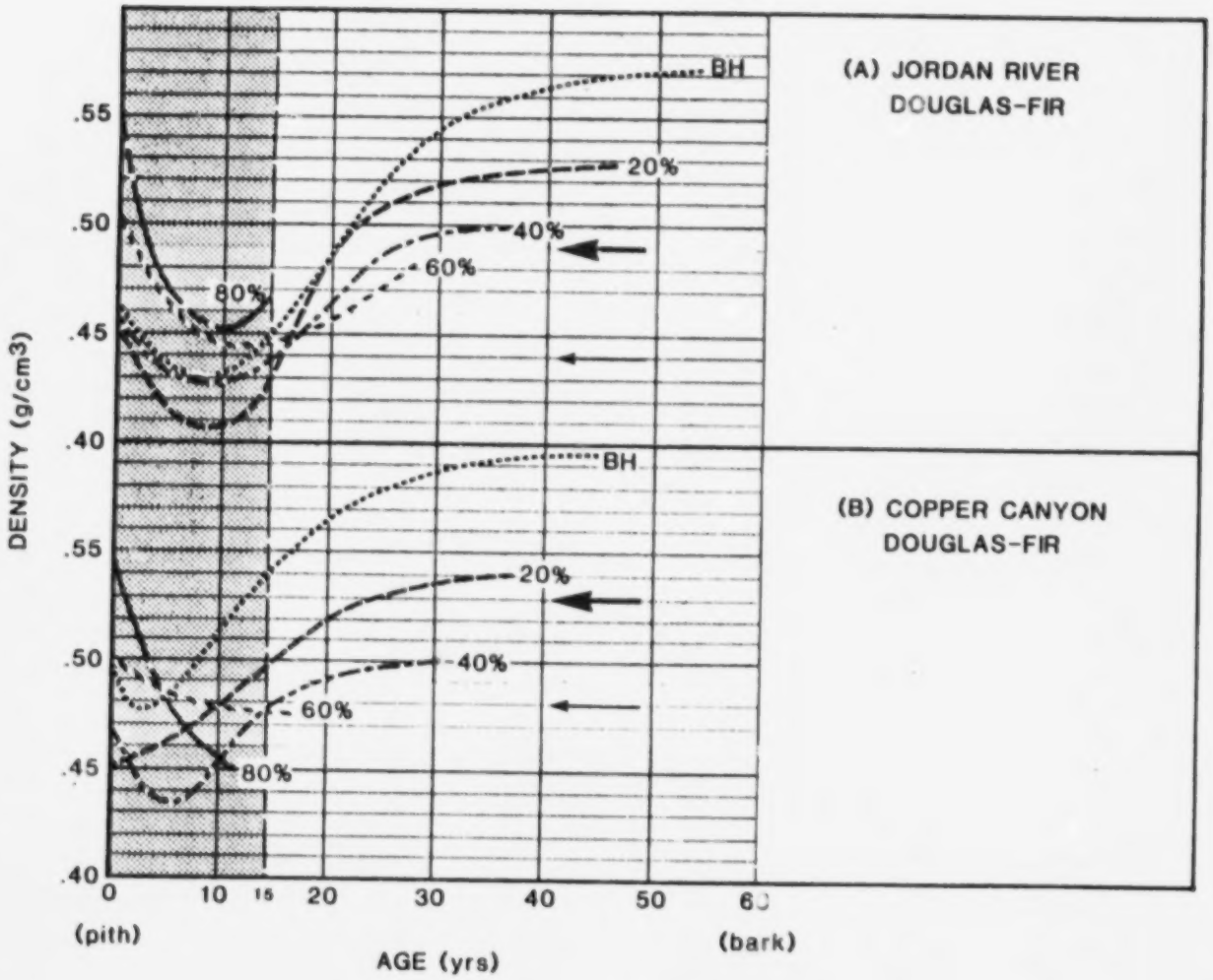



Figure 12 Average Annual Ring Density Trends at Five Sampling Heights for Two Coastal Sites, Jordan River (a) and Copper Canyon (b)

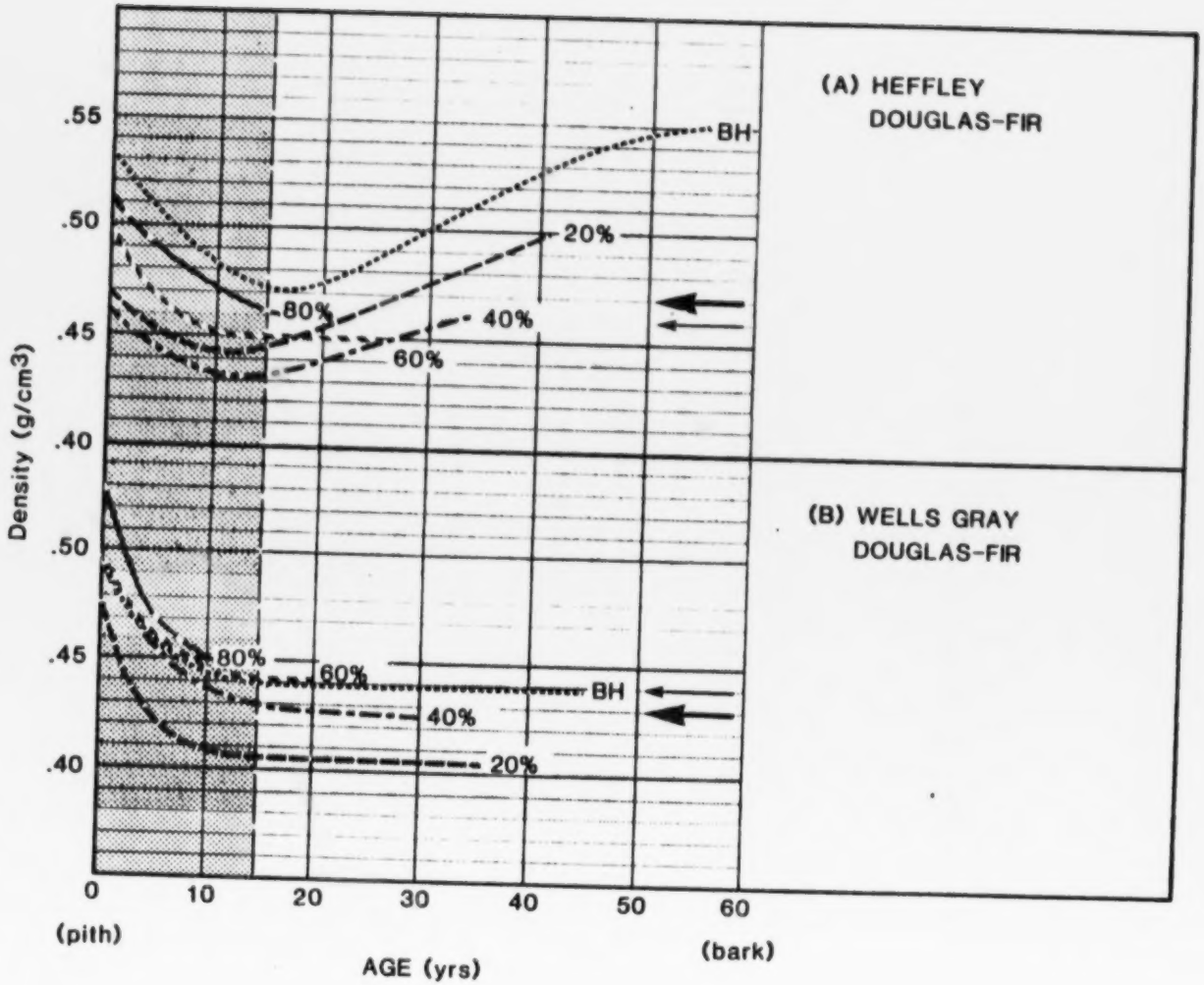



Figure 13 Average Annual Ring Density Trends at Five Sampling Heights for Two Interior Douglas-Fir Sites, Heffley (a) and Wells Gray (b)

height are only about two percent less dense than the entire stem-wood (0.46 compared with 0.47 g/cm$^3$). It also appears that if there is low density core-wood it is not immediately adjacent to the pith but it is formed, on the average, from age 10 to 20 (note the dip in the trend line of each sampling height in Figure 13a).

The Interior wet-belt Douglas-fir site at Wells Gray produced the most surprising density trends. There are three fundamentally different features noteworthy for this site in relation to the other five Douglas-fir sites (Figure 13a): (1) relatively high density core-wood; (2) very stable density trends at each sampling height from about the 10th ring to bark; (3) relatively low "hemlock-like" total stem-wood density at 0.43 g/cm$^3$. In fact, with the exception of the first two to seven years of growth (at each sampling height), the entire stem-wood can be classified as less dense than 0.46 g/cm$^3$.

The Interior wet-belt Douglas-fir site at Wells Gray was expected to parallel the Coastal sites (Jordan River and Copper Canyon) in its density trend from pith to bark. In this case, the fundamental site-to-site differences may be related to the temperature regime and the length of the growing season differences between the Coast and the Interior of B.C. On the Coast, trees photosynthesize almost year round, whereas in the continental climate of the Interior, trees are truly dormant (temperatures are below the freezing point) during the winter months. During the dormant season for trees in the Pacific Northwest (coast), substantial net photosynthesis occurs over a wide range of environments. Winter temperatures are mild and subfreezing day temperatures are uncommon, even in mountain environments. This is true of soil as well as air temperatures. Frozen soils are extremely rare, even in sub-alpine environments, thus water uptake is not a major problem (Waring and Franklin, 1979). The density differences between Coast and Interior Douglas-fir could be explained by these considerations, which directly affect the net photosynthates produced by the trees.

The above density results and discussions must be considered as exploratory in nature. Each site was represented by only five sample trees, with about a 20 percent range being observed between the most and the least dense tree at each site. However, the trends from pith to bark and the rankings (low to high density) were always consistent for each species at each site.

To conclude this section on pith-to-bark density trends, the high, low, and medium density stem-wood zones were mapped for Copper Canyon, Heffley, and Wells Gray Douglas-fir sites. The results are shown, along with the Jordan River site for comparison purposes, in Figure 14. The stem-wood longitudinal sections were drawn at the same scale to facilitate site to site comparisons. Total stem-wood density values are shown below the site names (bracketed) and the number of annual rings at each sampling height are indicated.

It can be seen again in Figure 14 that the greatest density is reached at BH, with the exception of Wells Gray, and at the 60 and 80 percent heights (see Table 1 and Figure 9, also). Minimum average stem-wood

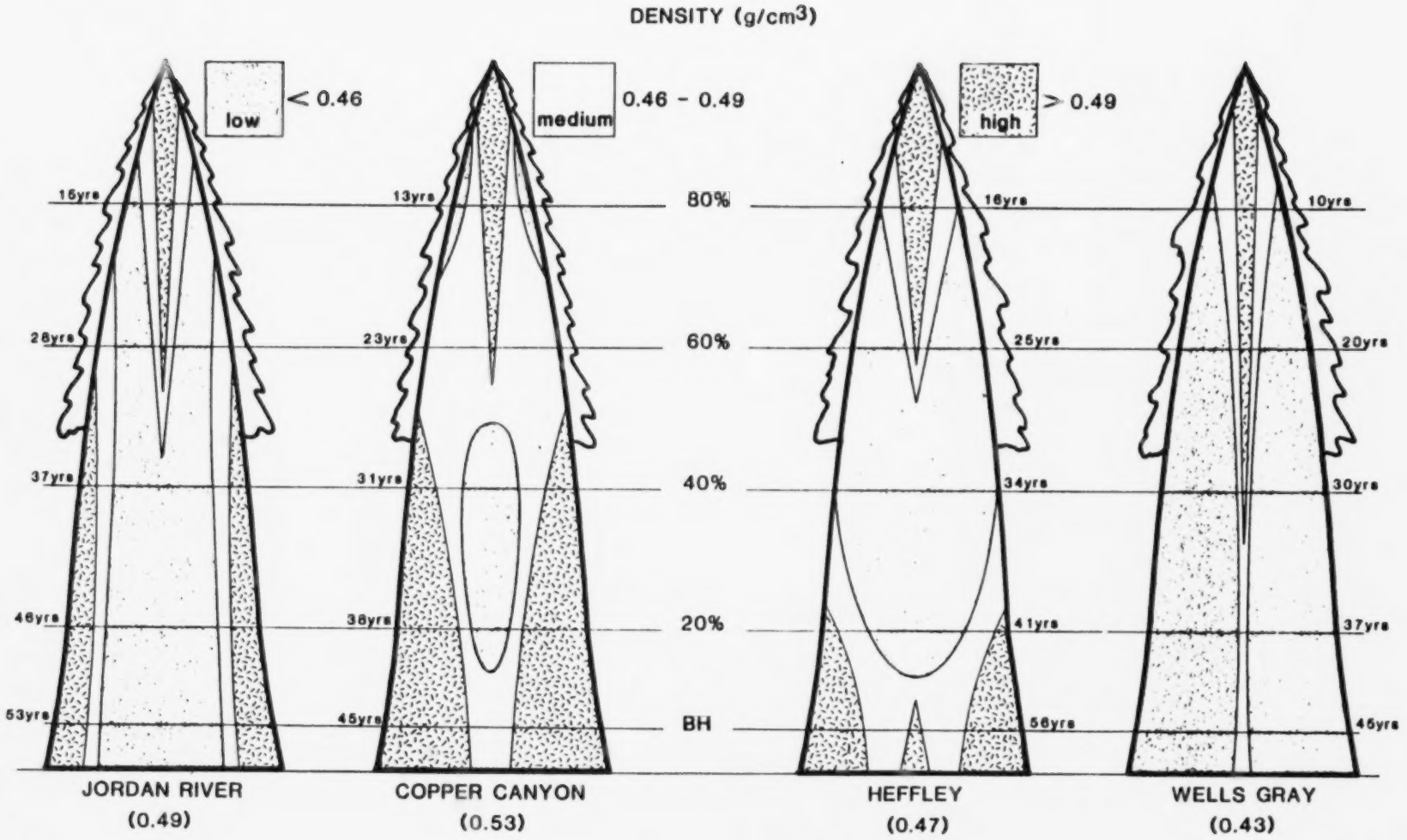



Figure 14 High, Low, and Medium Density Zones at Four Douglas-Fir Sites

density is at the 40 and 20 percent heights. Contrary to the marked total stem-wood density differences between these four sites, ranging from 0.43 to 0.53 g/cm$^3$, a certain degree of uniformity is evident above the 60 percent sampling height across the four sites. For example: at the 80 percent height average disc densities range from 0.44 to 0.47 g/cm$^3$ for these sites: Jordan River, 0.44; Copper Canyon, 0.46; Heffley, 0.47; and Wells Gray, 0.47 g/cm$^3$.

As was shown earlier for the Jordan River site, the more dense ($>$0.49 g/cm$^3$) "mature" wood extends from the base of the stem to about the base of the live crown for three sites (except the Wells Gray site). This type of density mapping, as shown in Figure 14, could prove very useful for studying the results of silvicultural treatments and in allocating the raw wood supply to specific end uses. Examples of this would be in pruning (either to "lift" the crown or to keep it low), pulping (more dense wood yields more solid fiber), and engineering applications (greater density means greater strength).

## 5.4 VOLUME GROWTH

Ultimately, when one describes the wood quality of different stands (of the same or different species) in terms of stem-wood density, one has to consider wood productivity as well. To make this transition smooth, from density to volume and weight, average stem-wood development histories are shown in Table 4 and Figure 15. The stem-wood density data are presented in terms of stem volume for the five species and 14 sites. In Figure 15 the three most noteworthy features are: (1) the relative ranking according to density; (2) the highly variable stem volumes as shown by the length of the trend lines (not unlike horizontal bar graphs of total stem volume); (3) the increasing, stable, and decreasing stem-wood density trends. These site average trend lines were made by the diagonal classification scheme which utilized tree-ring data from all sampling heights.

The Interior Douglas-fir sites produced average stem-wood volumes ranging from 0.73 to 0.92 m$^3$. The Coastal Douglas-fir sites, at about the same age (or younger) produced 2.12 to 3.70 m$^3$ stem volumes; about three times the size of the Interior trees. Interestingly, the Jordan River western hemlock, trees of the same age and growing in association with the Jordan River Douglas-fir, had an average stem volume of 3.1 m$^3$; about 16 percent smaller than the Douglas-fir. It is also interesting to note that the relatively high density core-wood for the Wells Gray Douglas-fir, from pith to age 10 (Figure 13), is only about 0.1 m$^3$ (11 percent of the total stem volume).

Table 4

Average Age, Individual Stem-Wood Volume, and YEARW Productivity Values for Five Species at 14 Sites

| | Douglas-Fir | | | | | | W. Hemlock | | Lodgepole P. | | I.Spruce | | W.R.Cedar | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jordan River | Copper Canyon | Heffley | Heffley Released* | Galena Released* | Wells Gray | Jordan River | Port McNeill | Wells Gray | Jacobie Creek | Wells Gray | Claude Lake | Horne Lake | Shawnigan R. |
| Age (years) | 53 | 45 | 60 | 105 | 100 | 45 | 55 | 35 | 48 | 77 | 49 | 95 | 48 | 66 |
| Density | 0.49 | 0.53 | 0.47 | 0.49 | 0.48 | 0.43 | 0.43 | 0.42 | 0.44 | 0.42 | 0.35 | 0.36 | 0.34 | 0.33 |
| Stem-Wood Volume ($m^3$) | 3.70 | 2.12 | 0.73 | 0.76 | 0.75 | 0.92 | 3.1 | 1.41 | 0.97 | 1.32 | 0.96 | 1.44 | 1.13 | 1.46 |
| YEARW (average of last five years) (kg) | 69 | 55 | 15 | 14 | 20 | 24 | 43 | 35 | 15 | 11 | 20 | 12 | 17 | 25 |

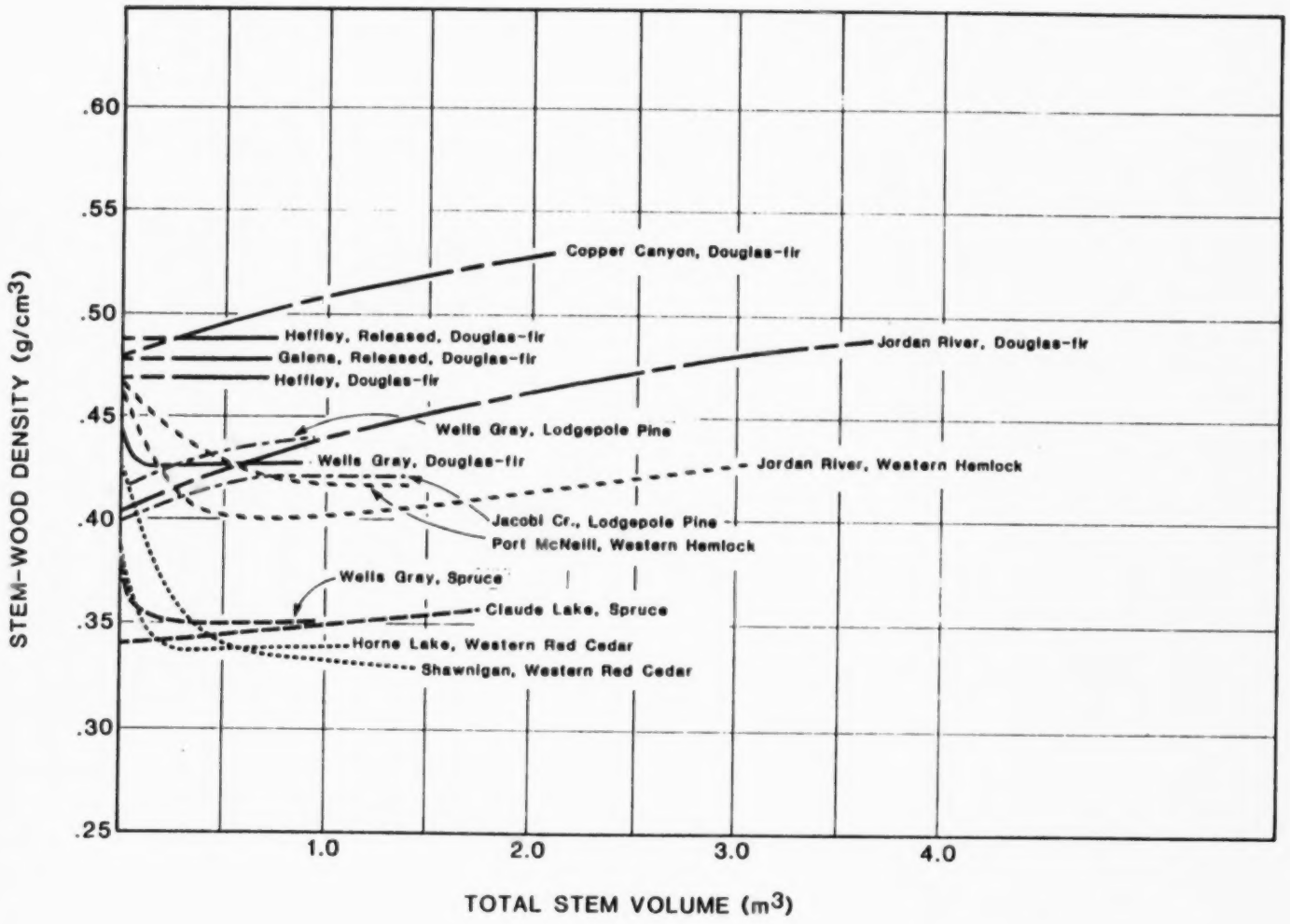



Figure 15 Stem-Wood Density Development in Terms of Stem Volume for Five Species and 14 Sites

## 5.5 WEIGHT OF ENTIRE ANNUAL INCREMENTS

Yearly entire annual ring weight (YEARW) trend lines were discussed briefly in the Jordan River Douglas-fir Results and Discussion section. In order to create a broader perspective, other Douglas-fir sites and other species will be discussed next.

The Copper Canyon Douglas-fir site, on the east coast of Vancouver Island, was the second most productive site on the individual sample tree basis (Figure 16). At this site, an average sample tree produced 49 kg of wood in 1982, equalling about 69 percent of the 8-years-older Jordan River final 1982 YEARW, which was 71 kg. However, these same trees at Copper Canyon laid down about 63 kg of wood in 1981 and 1980, which is about 89 percent of the 71 kg values for the final growth year at Jordan River. Interestingly, ring years 1980 and 1981 were also found to be superior in another recent study at Forintek, which dealt with the fertilization and thinning of a 37-year-old Douglas-fir stand at Shawnigan Lake (Jozsa et al., 1985). In that study, a strong positive relationship was identified between YEARW and May-June precipitation.

How do these final (1982) YEARW values from Vancouver Island compare with the two fast-grown Interior Douglas-fir sites? At Heffley (age 60) the five sample trees produced about 17 and at Wells Gray (age 45) about 25 kg of wood in 1983. These results are drastically different, especially since they were obtained for the same species of trees of similar age (Douglas-fir, about 51 years). What does this mean? When we describe wood quality in terms of density trends, productivity rate (quantity) should be considered as well.

In order to permit species-to-species and site-to-site YEARW productivity rate comparisons, site average trend lines were prepared (Figure 17). This was accomplished by drawing a smoothed running-mean trend line for each site from age one to the cutting age (35 to 105 years). (Compare in Figure 16 Copper Canyon sample trees' broken-line plots with the "smooth" Copper Canyon trend line; the year-to-year variation has been removed.) The vigorous Coastal sites are evident through the steep slope of their trend lines, particularly the Jordan River and Copper Canyon Douglas-fir. The eight-year age difference between these sites seems to account for the slightly lower YEARW productivity at Copper Canyon. The two western hemlock sites also show extremely vigorous growth, especially in their first 15-20 years; steep slope, then gradual decline. This decline is most evident when the Jordan River Douglas-fir trend line is compared with the Jordan River western hemlock. The two species have kept abreast in their early development, from the 1920's to about 1950. From 1950 to 1982 the Douglas-fir appears to have outperformed the western hemlock almost twofold (from 20 to 70 kg compared with 20 to 40 kg). Port McNeill western hemlock, with an average age of 35, follows much the same trend as the 55 year old Jordan River western hemlock (which also reached the 30 kg YEARW at age 35, in about 1962).

In Figure 17 the Interior lodgepole pine, Interior spruce, and Douglas-fir sites show relatively slow initial YEARW productivity

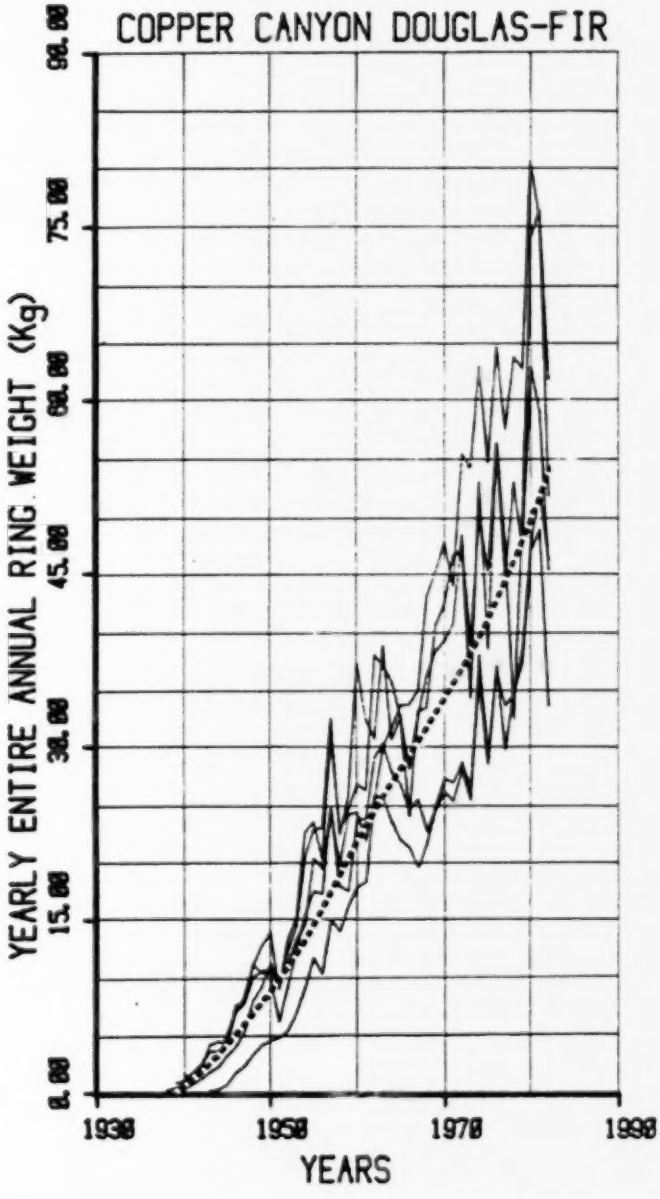



Figure 16 Yearly Entire Annual Ring Weight Record of Five Sample Trees from Copper Canyon from Age One (1920's) to Age 55 (1982)

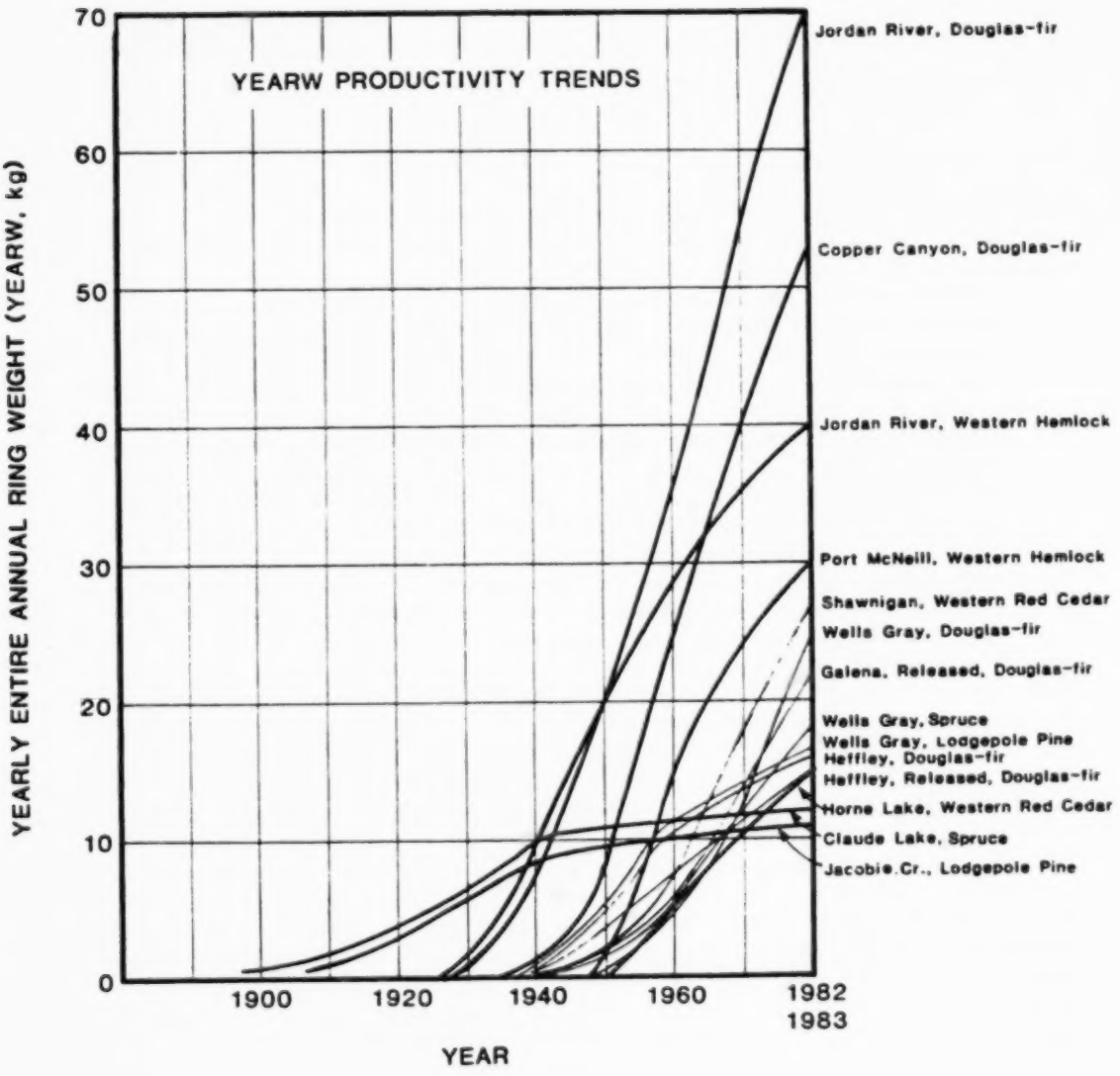



Figure 17 Running Mean of YEARW Productivity for 14 Sites from Age One to the Cutting Age (cut in 1982 or 1983)

rates (shallow trend line angles). The two most stagnant sites appear to be the Claude Lake Interior spruce and the Jacobie Creek lodgepole pine stands; slow initial YEARW development was followed by an even slower productivity rate increase.

Detailed YEARW trend lines, showing the five sample trees from each of the 14 sites, are shown in Appendix II. Strong cross-dating is evident for each species at each site indicating a climatic connection. The "good" and "bad" climate years are being experienced by the trees in unison.

## 5.6 FUTURE RESEARCH

Sutton (1984), at the end of an excellent lecture on research and manufacturing experience with radiata pine in New Zealand, stated:

> "Are there lessons too for British Columbia in the New Zealand experience? I believe there are. You are now where we were at the turn of this century. You still have large areas of mature forests but you are becoming aware of future supply problems. Expansion is not possible and even sustention will be difficult. You are uncertain about how to manage the second growth forest.
>
> You desperately need a major review of your collective management and research experience. You must use this and a whole series of new studies, especially at the interface between the trees and processing, to provide a means of monitoring what you have and what are your alternatives."

This research is part of such a review. The effort has been concerned with B.C. species to begin with. However, the entire process must be repeated on a national scale: for all commercially important Canadian species and their markets. The cooperation of other agencies and research institutes must be assessed before this difficult and extensive research is performed. One particular research institute is that for pulp and paper (P.P.R.I.C.).

Zobel and Kellison (1984) have discussed the effects of increasing juvenile wood furnish to the pulp and paper industry. They stated that:

> "Although pulp yields are adversely affected, juvenile wood is preferable for some tissue and fine paper products and for newsprint. The greatest limitation to increased amounts of juvenile wood is that the industry must learn how to efficiently utilize the raw material in the manufacture of saleable products. For example, kraft paper made from young tropical pines is so poor in tear strength that the paper is not saleable on the world market, and solid-wood products made from juvenile wood are weak and unstable. Yet for thermomechanical pulp and newsprint, juvenile wood is highly desirable, just as it is for fine writing papers."

If this is indeed the same for northwestern fast-grown trees (Zobel and Kellison were discussing southern U.S.A. species) then industry can plan now to send the corewood from our trees to the thermomechanical pulping plants. Thus, lumber products would be manufactured to include a maximum amount of sapwood and most recently formed heartwood, and the relatively small amounts of juvenile wood (boxed about the pith) would be pulped. Future research into the feasibility of such schemes needs to be performed in cooperation with the Pulp and Paper Research Institute of Canada.

## 6.0 SUMMARY AND CONCLUSIONS

Average yearly ring density trends were examined by X-ray densitometry from pith-to-bark at five sampling heights for five sample trees of second-growth Coastal Douglas-fir (two sites), Interior Douglas-fir (two fast-grown and two released sites), Coastal western hemlock (two sites), Interior lodgepole pine (two sites), Interior spruce (two sites), and Coastal western red cedar (two sites). From a stand management perspective our attention was focussed on describing juvenile wood characteristics based on wood density. From the utilization perspective of wood and fiber, average ring density variation was examined within-tree, tree-to-tree, and site-to-site.

In this study we referred to juvenile wood as the innermost region of 15 annual rings; the inner cylinder of wood that surrounds the pith from the base to the top of the stem-wood. Annual rings close to the pith tended to be wide with comparatively high density wood for the initial years and then a decreasing specific gravity trend was found for the next few ring-years. This density pattern was found to last for about 5 to 10 years in Douglas-fir (0.50 to 0.45); about 10 years in western hemlock (0.55 to 0.40), Interior spruce (0.42 to 0.36) and Coastal western red cedar (0.40 to 0.33). Interior lodgepole pine showed little density variation.

Low density juvenile wood was found in Coastal Douglas-fir and western hemlock from about the 5th to 15th, and 11th to 20th rings from the pith, respectively. Average ring density then increased steadily to about the 30th ring for both species at all heights, but the rise occurred fastest at BH. The density of the outer mature wood (more than about 25 rings from the pith) was highest at BH. At the 20 and 40 percent sampling heights, average density of the mature wood was about 10 and 20 percent lower than at BH, respectively.

In fast-grown, Interior wet-belt Douglas-fir, released Douglas-fir, Interior spruce, and Coastal western red cedar, juvenile wood was about five percent higher in density at all sampling heights than the more mature outer wood. For these species the flat trend-lines of average ring density from the 15th ring to the bark suggest no relationship between growth rate and specific gravity.

Within-tree average ring density variation ranged from 10 to 40 percent due to juvenile-mature wood differences. The percentage

density variation range for each species was as follows: Interior lodgepole pine and Interior wet-belt Douglas-fir, 10; Interior spruce, 15; Interior released Douglas-fir, 20; Interior dry-belt Douglas-fir and coastal western red cedar, 30; and Coastal western hemlock and Douglas-fir about 40 percent.

Douglas-fir showed a great diversity in average stem-wood density (0.38 - 0.54 $g/cm^3$) and density distribution in the stem-wood, which were both thought to be biogeoclimatically induced. Paradoxically, a high degree of uniformity was observed in juvenile wood (first 15 rings) density of Douglas-fir from the base to the top of the stem at each site. The average juvenile wood density for the six Douglas-fir sites was 0.46, ranging from 0.44 to 0.48.

Based on an arbitrary density level of $> 0.49$ $g/cm^3$, the mature wood in Douglas-fir extended from the base of the stem to about the base of the live crown.

Tree-to-tree average stem-wood density variation was about 20 percent for the five species examined. For each species at each site individual trees could be ranked according to density as early as age five, but at about age 15 the rankings were more reliable. The density rankings suggest that it is possible to have both rapid growth and high density through genetic selection.

Coastal Douglas-fir sites produced higher density wood than the Interior sites, 0.51 compared with 0.47. The coastal sites were more vigorous biomass producers than the Interior sites (as expressed by entire annual ring weights in the stem-wood).

This work was carried out as a first step to characterize the second-growth timber resource. Strong evidence points to a forest management strategy designed to maximize piece size and product value in the shortest possible time which will result in rapid growth rates. From a stand management perspective, more attention should be given to modelling factors that determine crown characteristics, because if problems exist with juvenile wood, they will be most serious in those stem portions formed within live crowns.

Density losses due to excessive juvenile wood production and rapid growth for Douglas-fir and western hemlock may be completely or partially overcome by selection of proper genetic stock. Any tree improvement program should consider wood density as one of the important parameters. At the very least, candidate plus trees displaying low density (for example one to two standard deviations below the mean for the species) should be culled in favor of higher density selections.

At best, the term juvenile wood was used only as a convenience. Average ring density values and trends from pith-to-bark were on a continuum at each sampling height for each species. With the exception of Coastal Douglas-fir and western hemlock, the changes in density were gradual. The changes in pith-to-bark density trends seemed to be age-related and not a function of distance from the pith, for all five species.

## 7.0 ACKNOWLEDGEMENTS

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Trevor G. Jeanes and Keith Brown, Balco Industries Ltd.; Ken Donkersley, CIP Forest Products Inc.; Don Pigott, Consultant; R.J. (Jack) Lavis and Gabriella Sartisohn, MacMillan Bloedel Ltd.; Ian Brown, M.E. (Mel) Monteith and Alan Wyse, Ministry of Forests, Province of British Columbia; John Barker and Bill McMullan, Western Forest Products Ltd.

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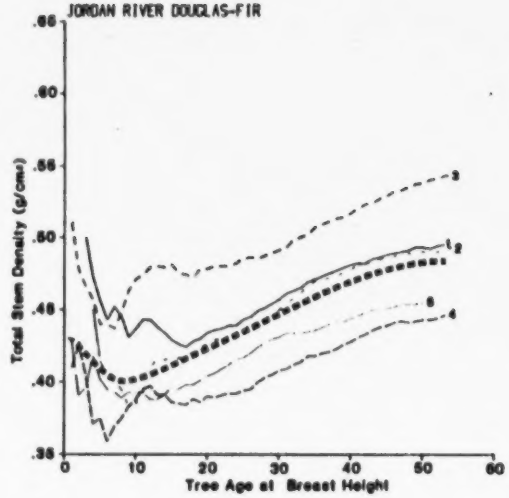
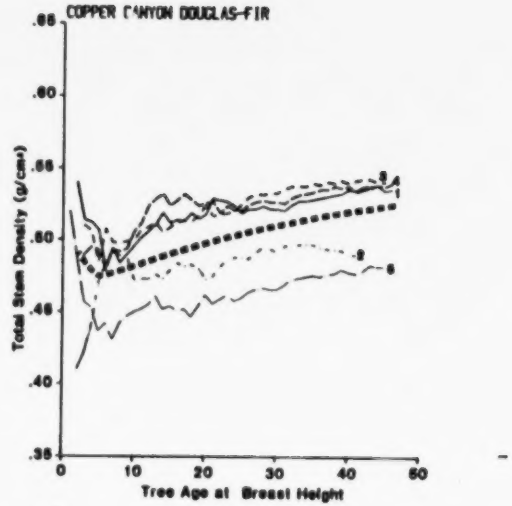
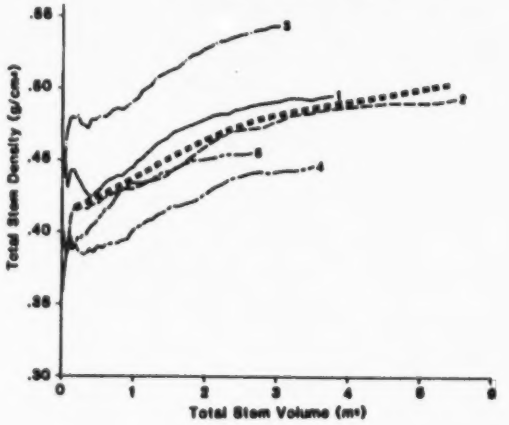
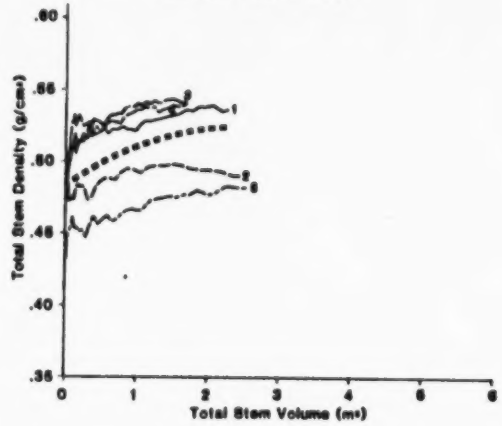
# APPENDIX I

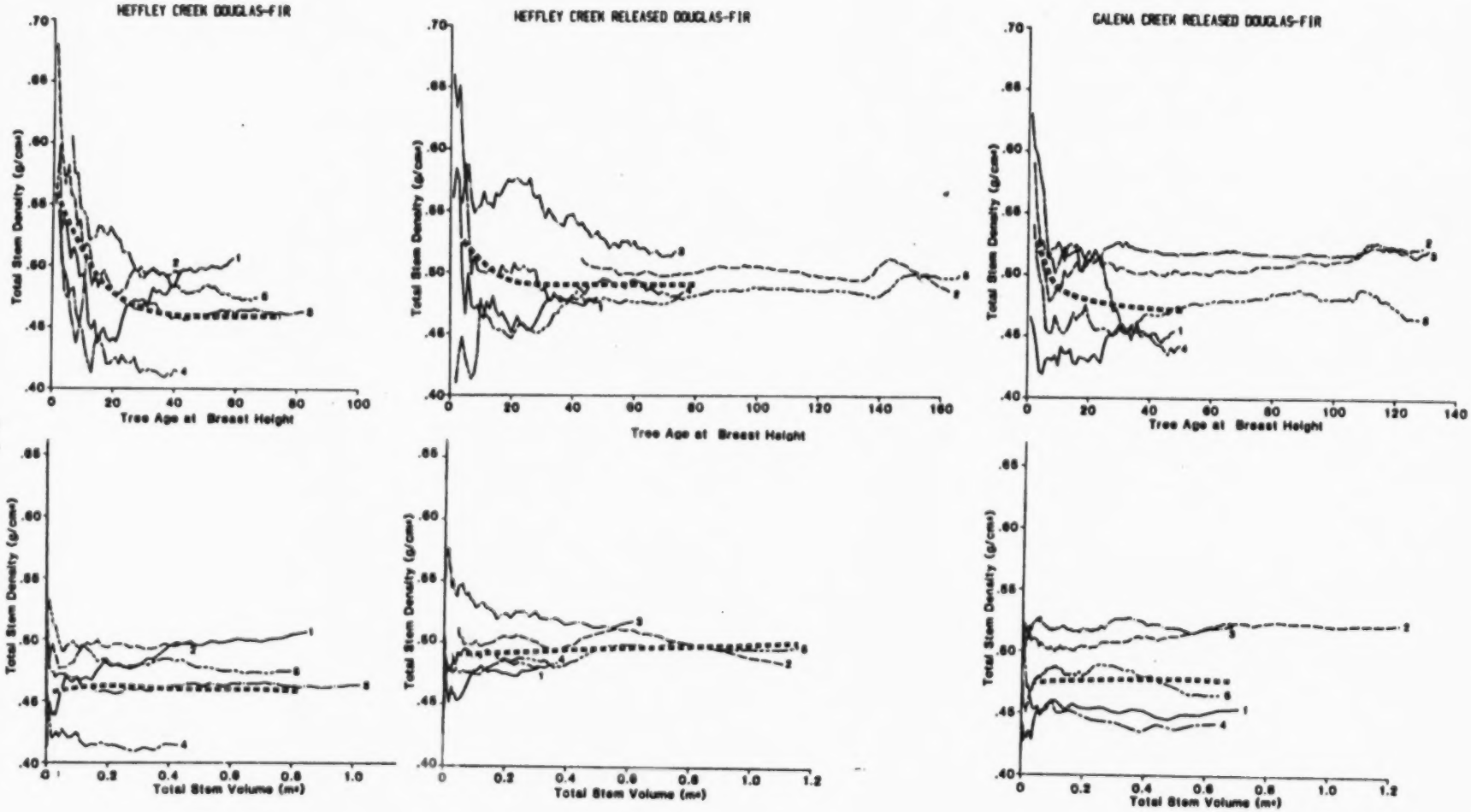
## PLOTS OF TOTAL STEM DENSITY TRENDS AS A FUNCTION OF AGE AT BH AND STEM VOLUME

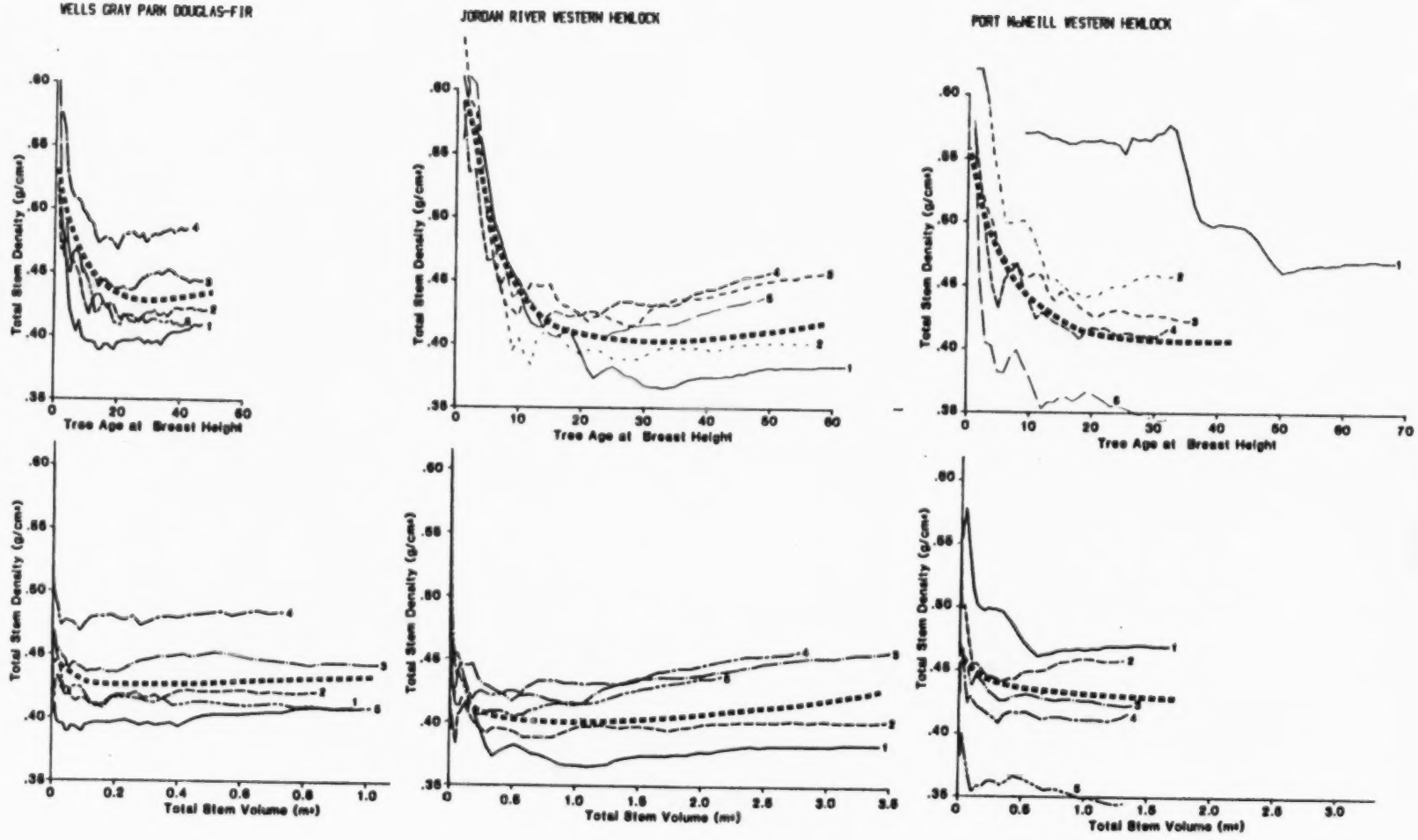

JORDAN RIVER DOUGLAS-FIR
Total Stem Density (g/cm³)
.65
.60
.55
.50
.45
.40
.35
0
10
20
30
40
50
60
Tree Age at Breast Height
3
1
2
5
4

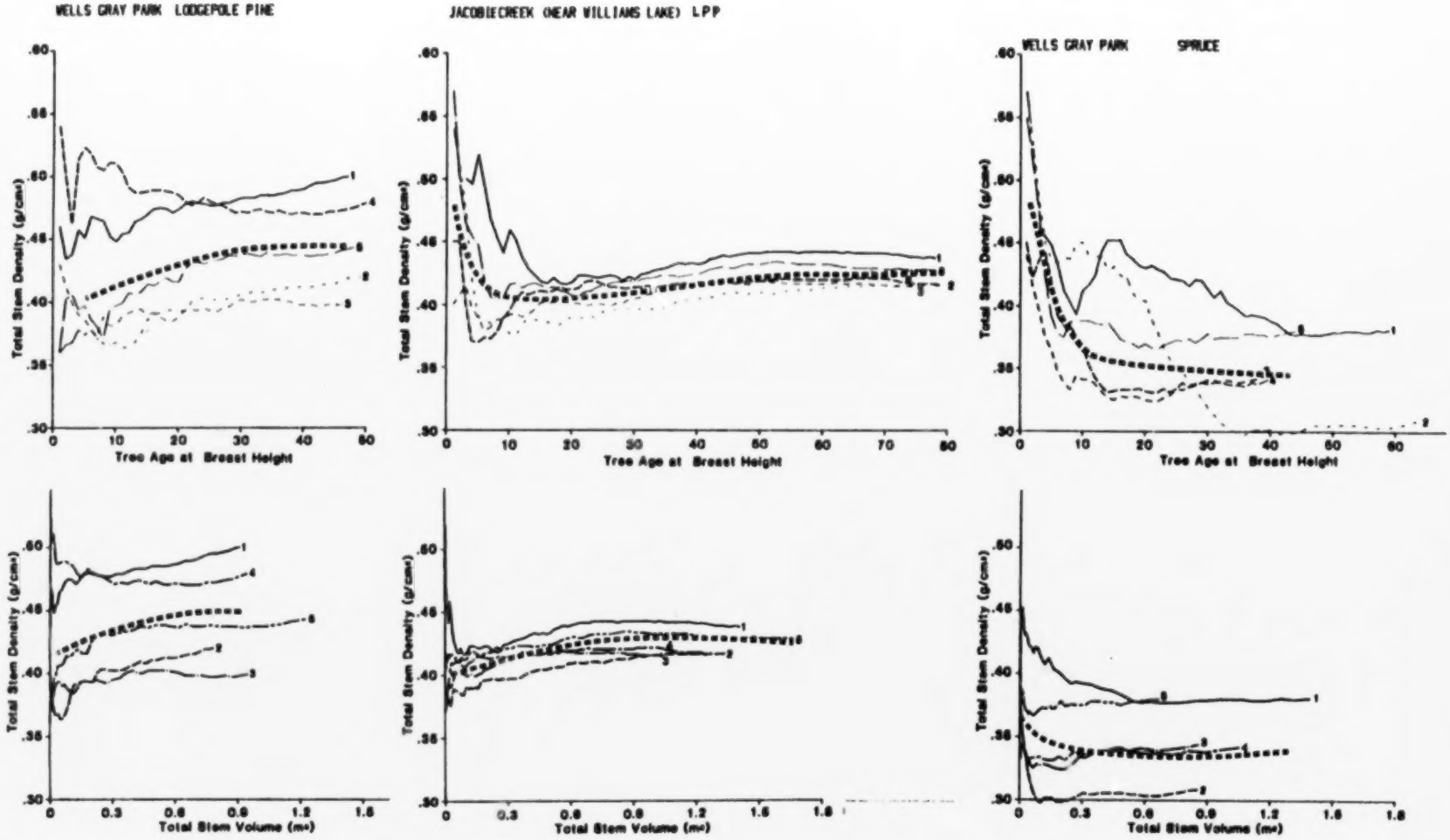

COPPER CANYON DOUGLAS-FIR
Total Stem Density (g/cm³)
.65
.60
.55
.50
.45
.40
.35
0
10
20
30
40
50
Tree Age at Breast Height
3
4
1
2
5

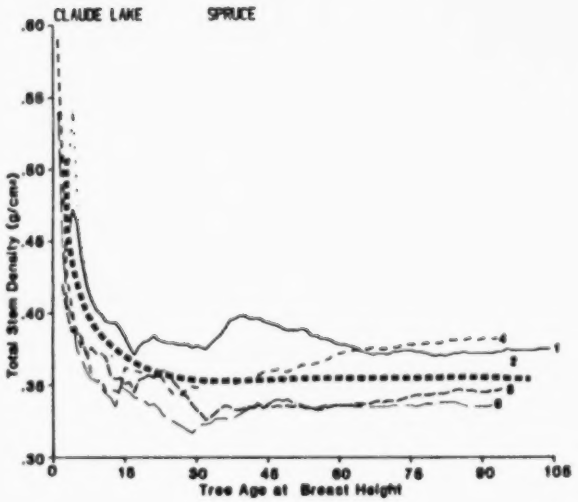

Total Stem Density (g/cm³)
.65
.60
.55
.50
.45
.40
.35
.30
0
1
2
3
4
5
6
Total Stem Volume (m³)
3
1
2
5
4

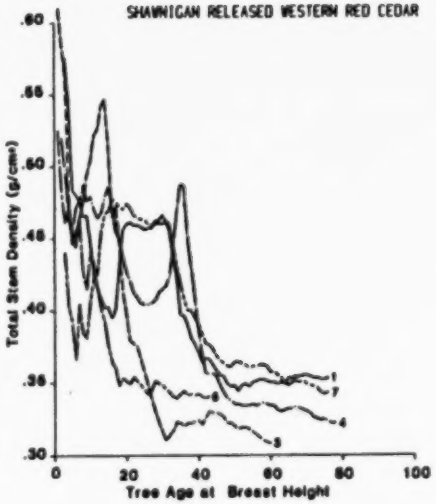

Total Stem Density (g/cm³)
.60
.55
.50
.45
.40
.35
0
1
2
3
4
5
6
Total Stem Volume (m³)
3
4
1
2
5

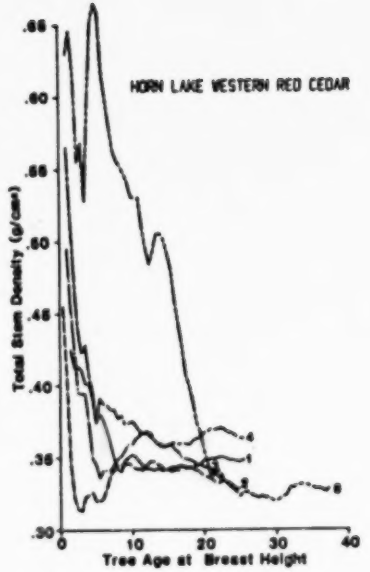

HEFFLEY CREEK DOUGLAS-FIR
HEFFLEY CREEK RELEASED DOUGLAS-FIR
GALENA CREEK RELEASED DOUGLAS-FIR
Total Stem Density (g/cm³)
Tree Age at Breast Height
Total Stem Volume (m³)

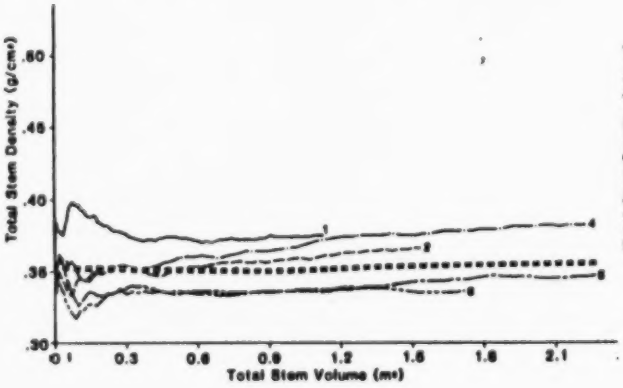

WELLS GRAY PARK DOUGLAS-FIR
JORDAN RIVER WESTERN HEMLOCK
PORT McNEILL WESTERN HEMLOCK
Total Stem Density (g/cm³)
Tree Age at Breast Height
Total Stem Volume (m³)

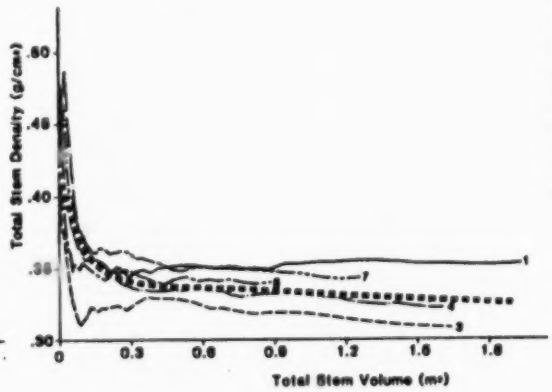

WELLS GRAY PARK LODGEPOLE PINE
JACOBIECREEK (NEAR WILLIAMS LAKE) LPP
WELLS GRAY PARK SPRUCE
Total Stem Density (g/cm³)
Tree Age at Breast Height
Total Stem Volume (m³)

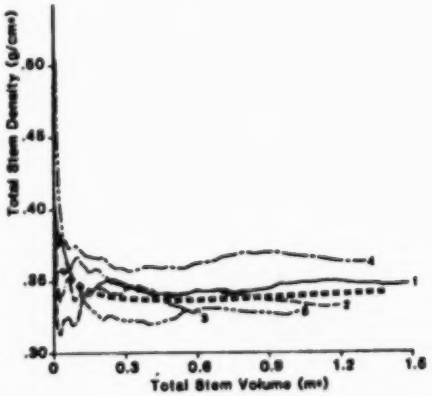

CLAUDE LAKE SPRUCE
Total Stem Density (g/cm³)
Tree Age at Breast Height


SHAWNIGAN RELEASED WESTERN RED CEDAR
Total Stem Density (g/cm³)
Tree Age at Breast Height


HORN LAKE WESTERN RED CEDAR
Total Stem Density (g/cm³)
Tree Age at Breast Height

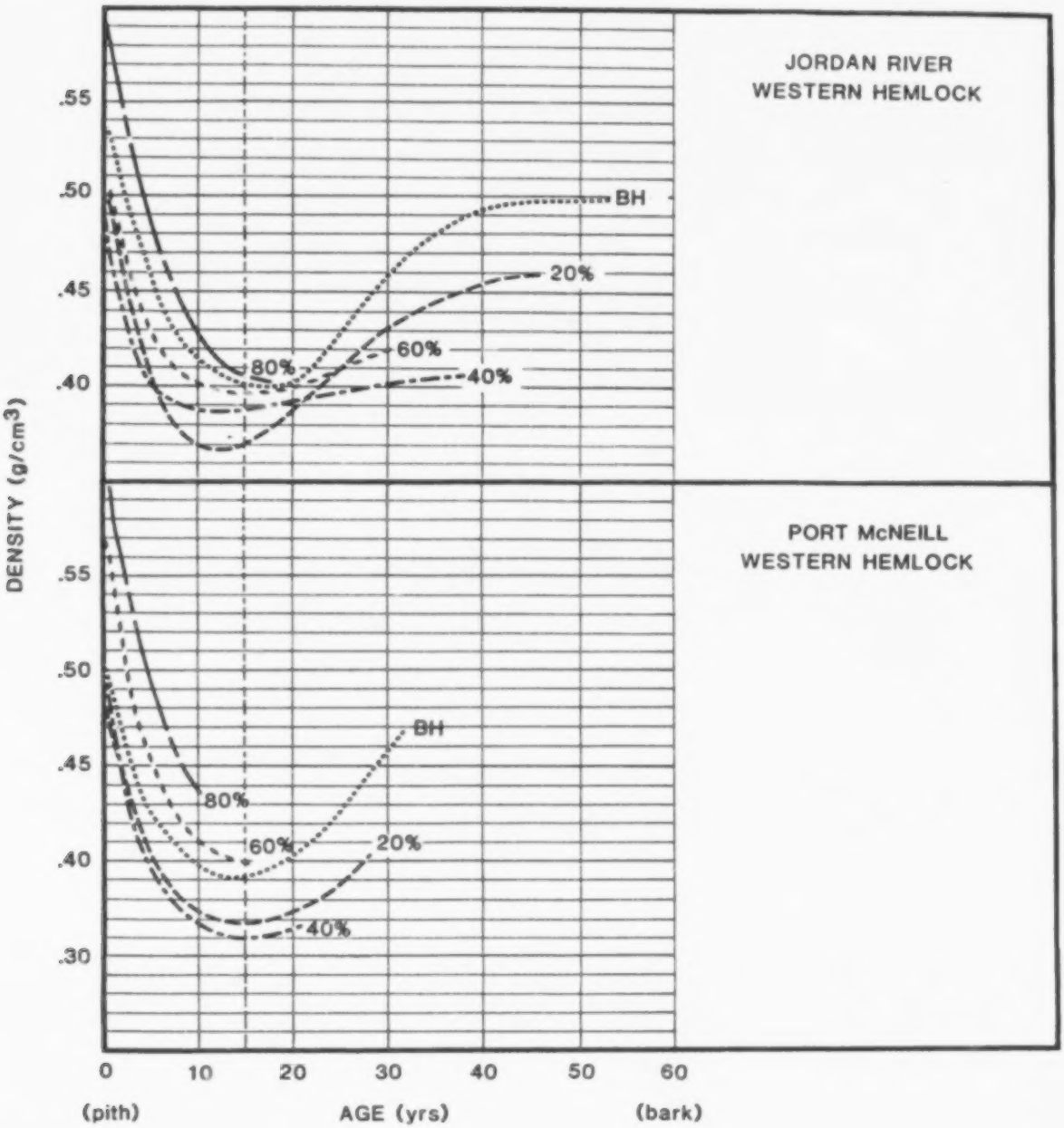

Total Stem Density (g/cm³)
Total Stem Volume (m³)

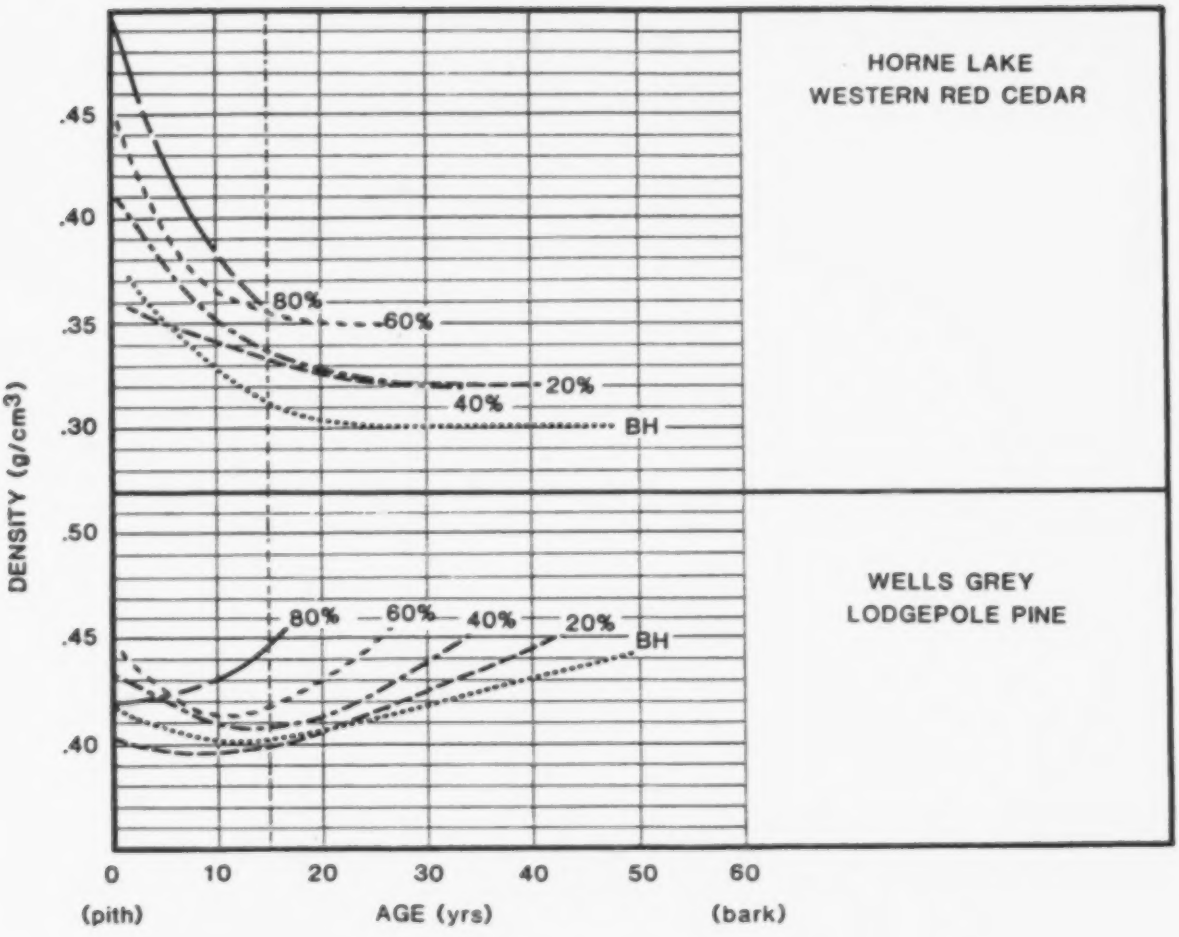

Total Stem Density (g/cm³)
Total Stem Volume (m³)

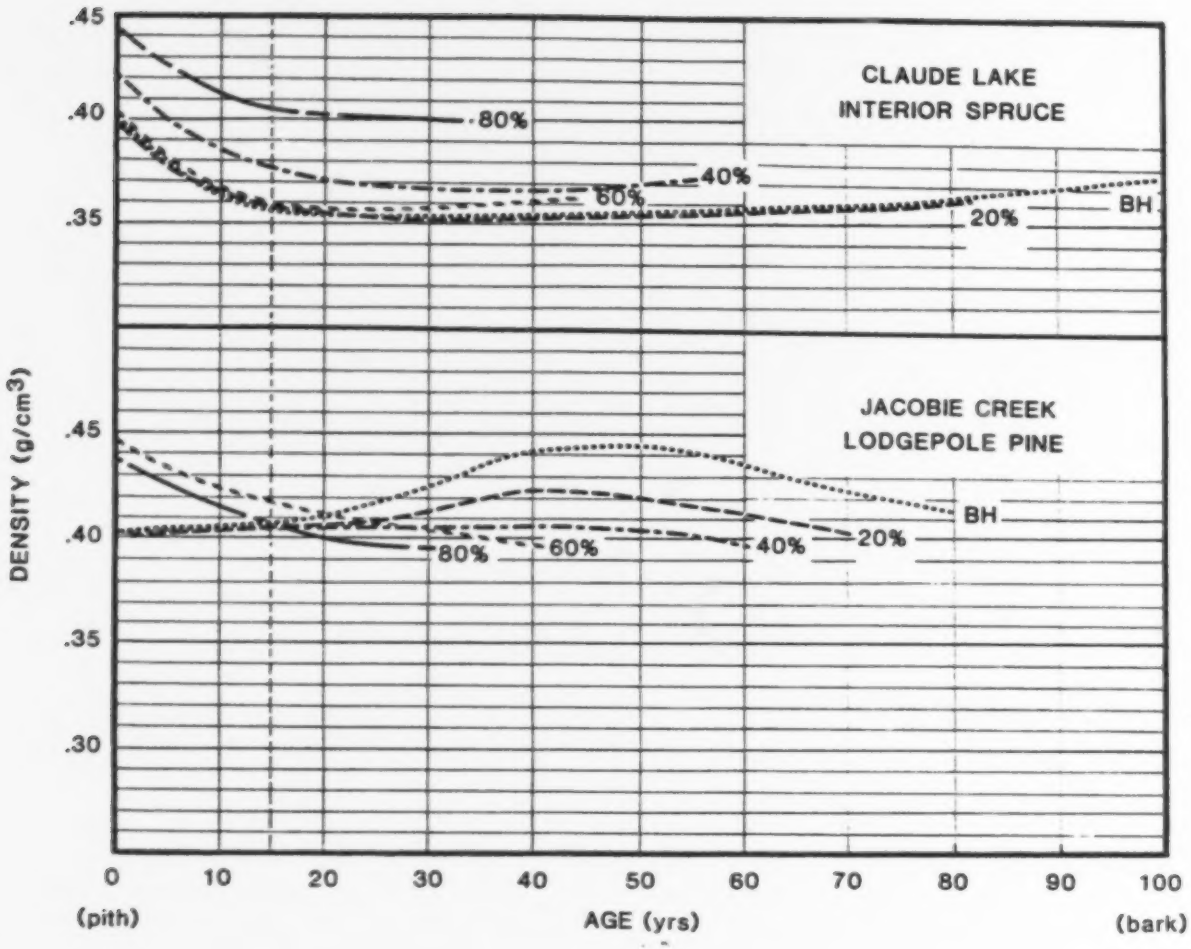

Total Stem Density (g/cm³)
Total Stem Volume (m³)

# APPENDIX II

## PLOTS OF PITH-TO-BARK AVERAGE ANNUAL RING-DENSITY TRENDS AT FIVE SAMPLING HEIGHTS FOR COASTAL WESTERN HEMLOCK AND WESTERN RED CEDAR, AND INTERIOR SPRUCE AND LODGEPOLE PINE

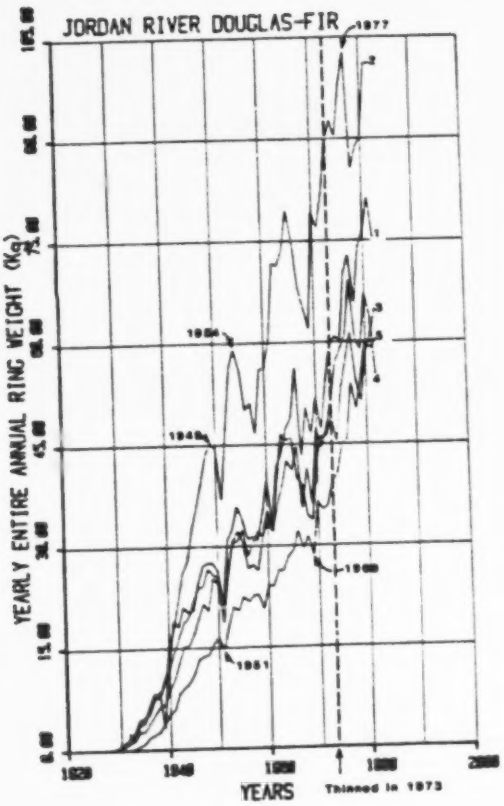

JORDAN RIVER
WESTERN HEMLOCK
PORT McNEILL
WESTERN HEMLOCK
DENSITY (g/cm3)
.55
.50
.45
.40
.30
BH
20%
60%
40%
80%
0
10
20
30
40
50
60
(pith)
AGE (yrs)
(bark)

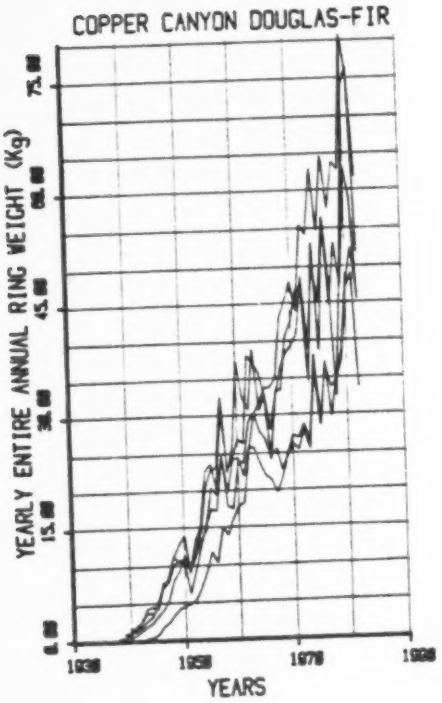

HORNE LAKE
WESTERN RED CEDAR
.45
.40
.35
.30
80%
60%
20%
40%
BH
WELLS GREY
LODGEPOLE PINE
.50
.45
.40
80%
60%
40%
20%
BH
DENSITY (g/cm3)
0
10
20
30
40
50
60
(pith)
AGE (yrs)
(bark)

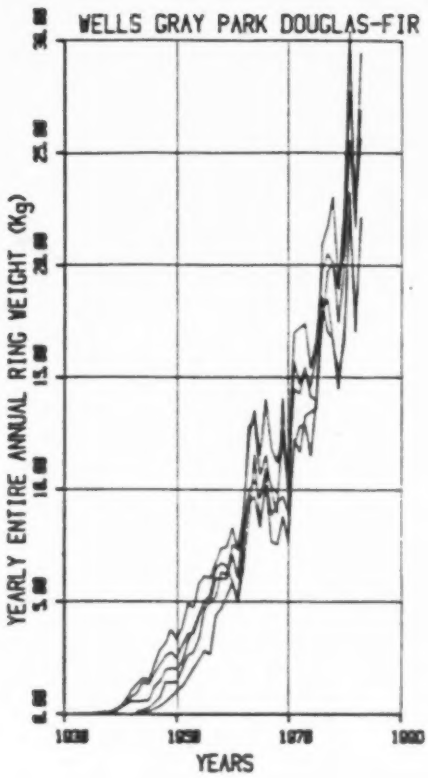

CLAUDE LAKE
INTERIOR SPRUCE
80%
60%
40%
20%
BH
JACOBIE CREEK
LODGEPOLE PINE
BH
20%
40%
60%
80%
DENSITY (g/cm3)
.45
.40
.35
.45
.40
.35
.30
0
10
20
30
40
50
60
70
80
90
100
(pith)
AGE (yrs)
(bark)

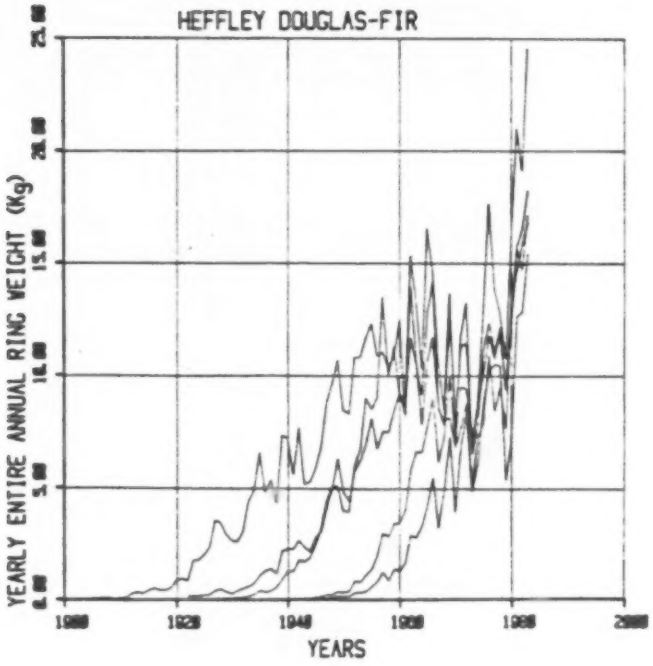
# APPENDIX III

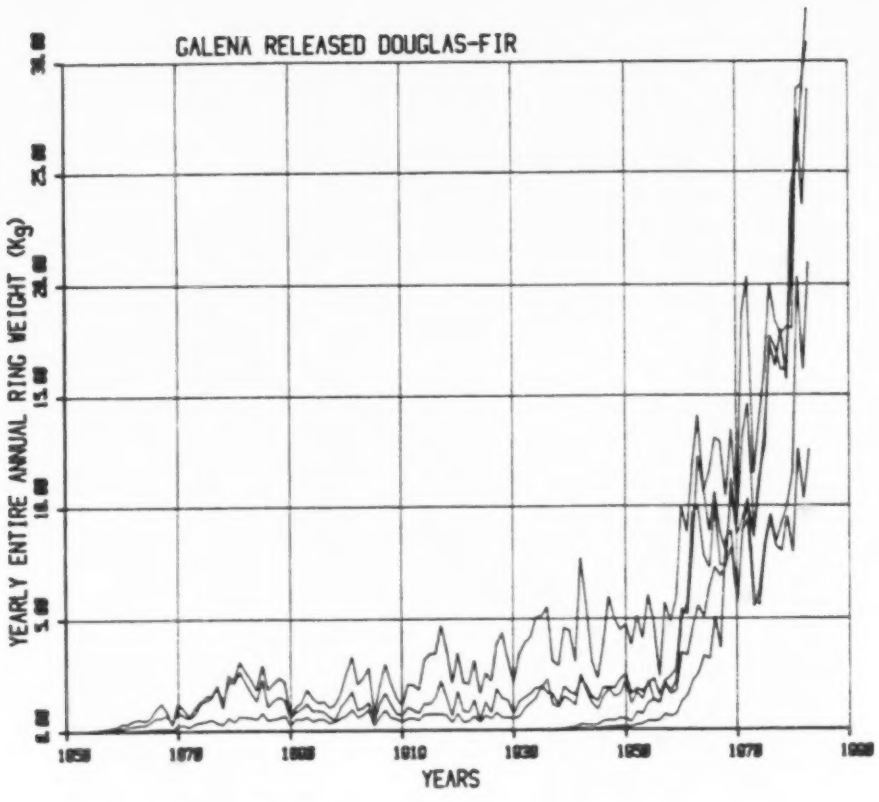
## PLOTS OF DETAILED YEARW TREND LINES FOR INDIVIDUAL SAMPLE TREES

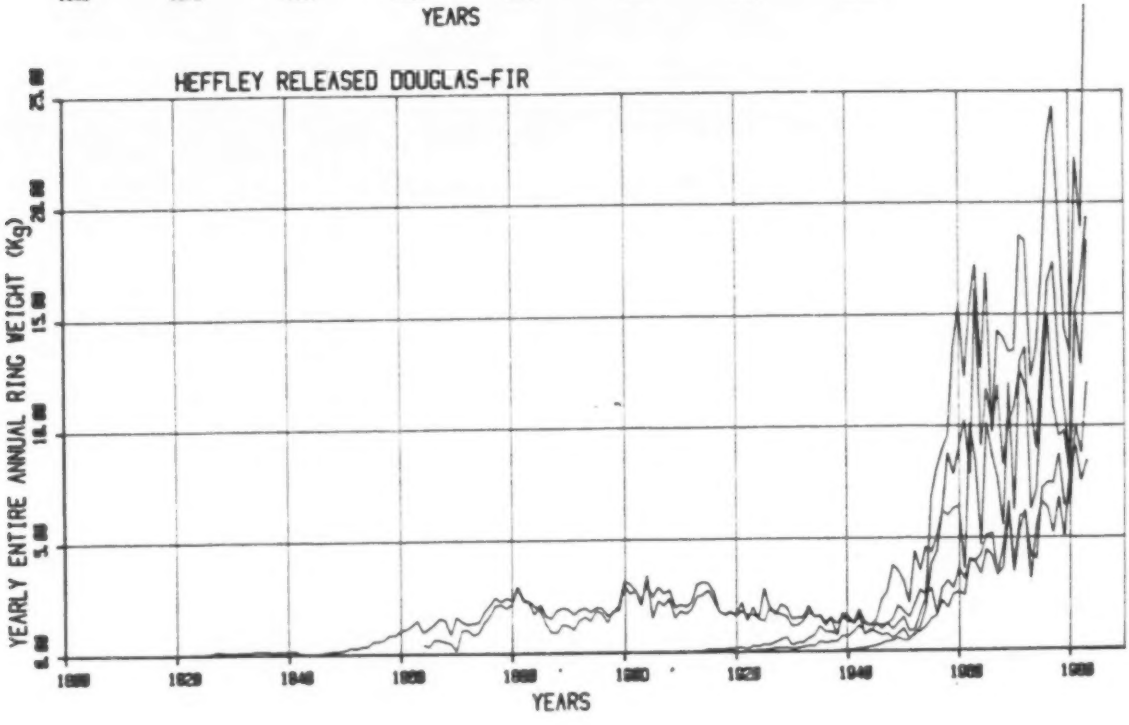

JORDAN RIVER DOUGLAS-FIR
YEARLY ENTIRE ANNUAL RING WEIGHT (Kg)
YEARS
Thinned in 1973

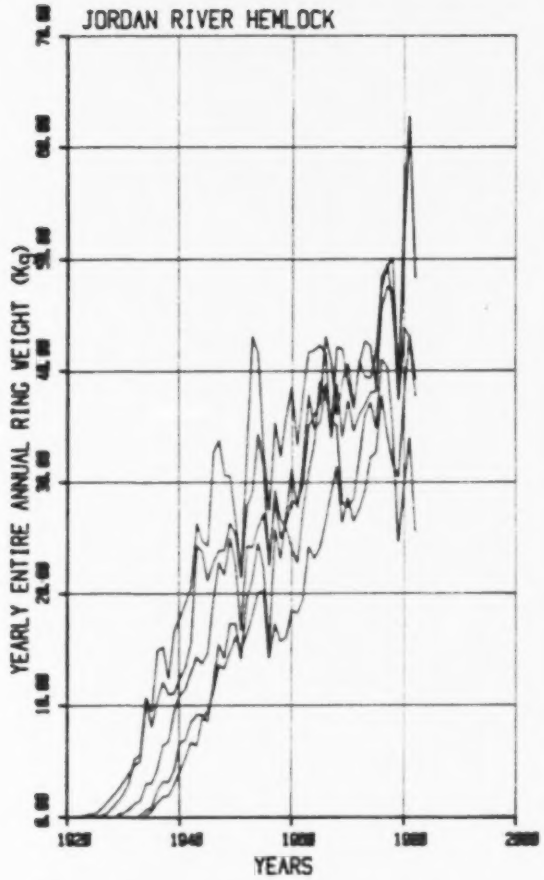

COPPER CANYON DOUGLAS-FIR
YEARLY ENTIRE ANNUAL RING WEIGHT (Kg)
YEARS

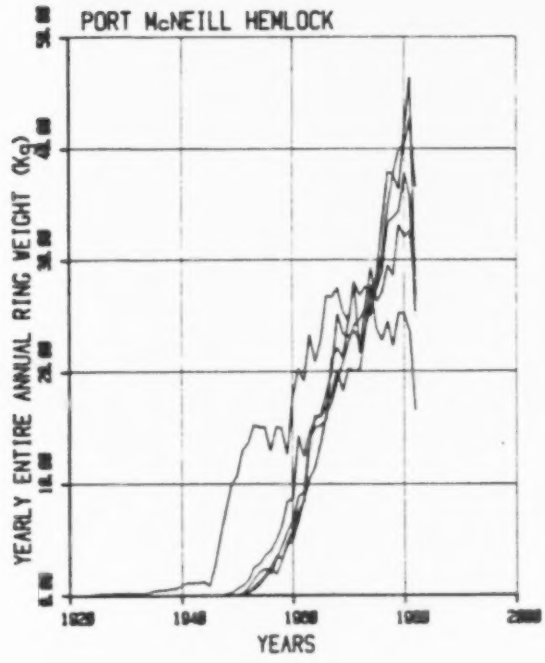

WELLS GRAY PARK DOUGLAS-FIR
YEARLY ENTIRE ANNUAL RING WEIGHT (Kg)
YEARS


HEFFLEY DOUGLAS-FIR
YEARLY ENTIRE ANNUAL RING WEIGHT (Kg)
YEARS

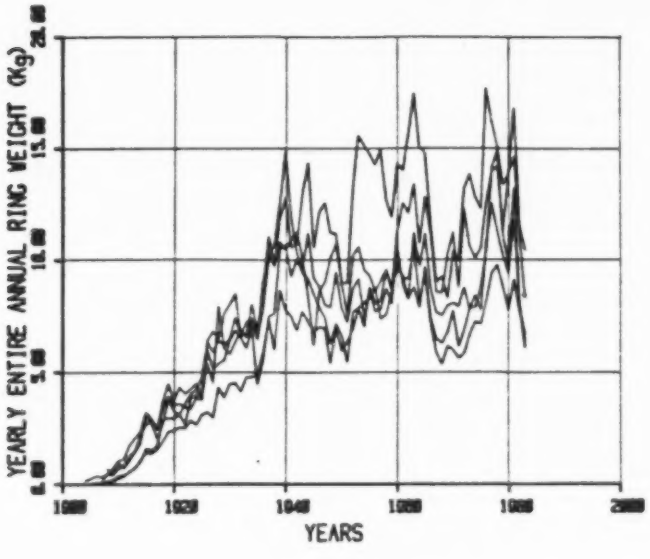

GALENA RELEASED DOUGLAS-FIR
YEARLY ENTIRE ANNUAL RING WEIGHT (Kg)
YEARS


HEFFLEY RELEASED DOUGLAS-FIR
YEARLY ENTIRE ANNUAL RING WEIGHT (Kg)
YEARS

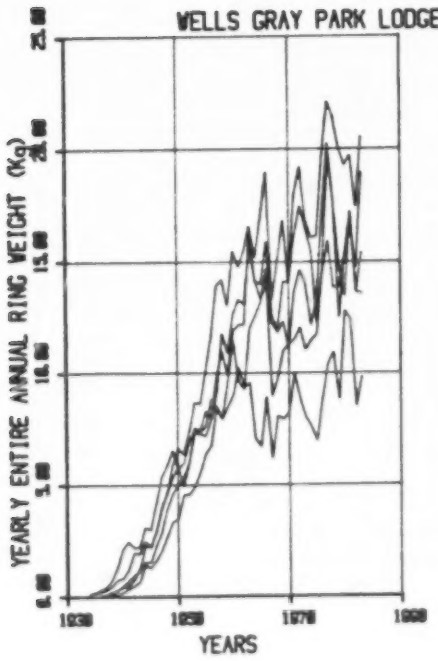

JORDAN RIVER HEMLOCK
YEARLY ENTIRE ANNUAL RING WEIGHT (Kg)
YEARS

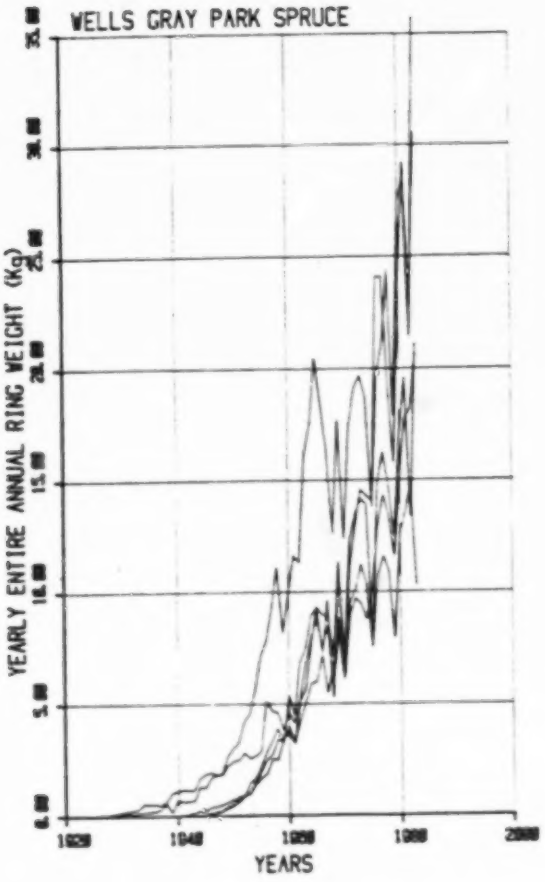

PORT McNEILL HEMLOCK
YEARLY ENTIRE ANNUAL RING WEIGHT (Kg)
YEARS

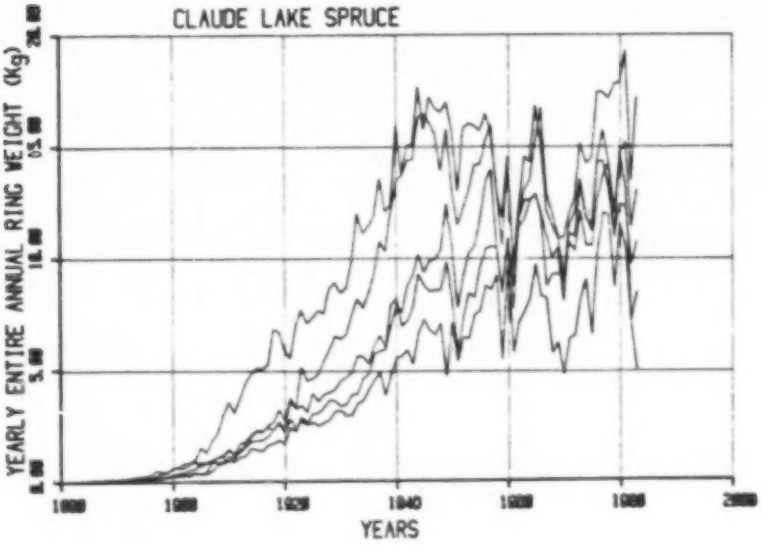
JACOBIECREEK LODGEPOLE PINE

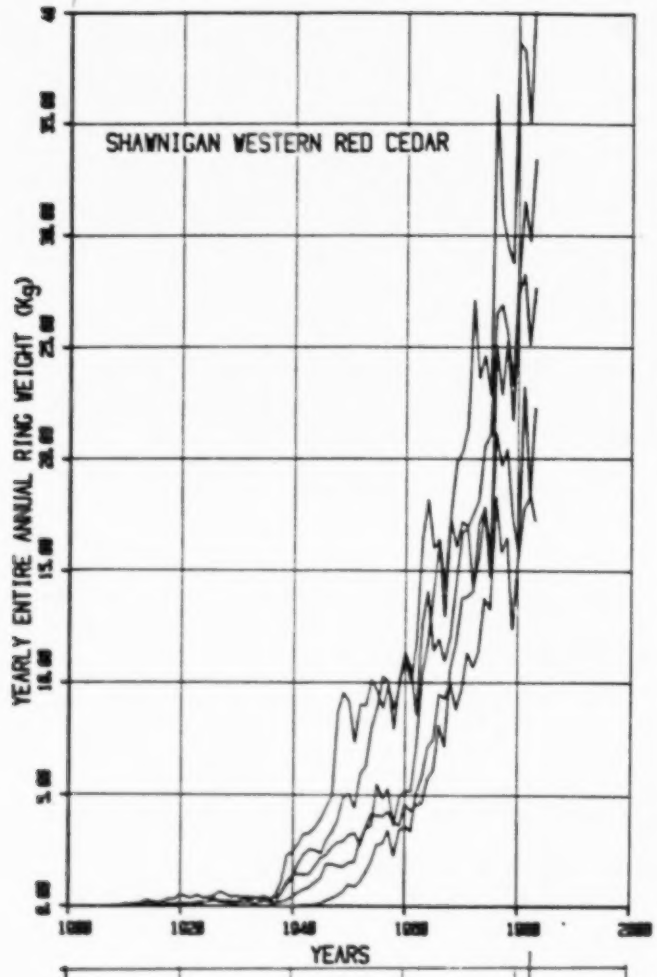


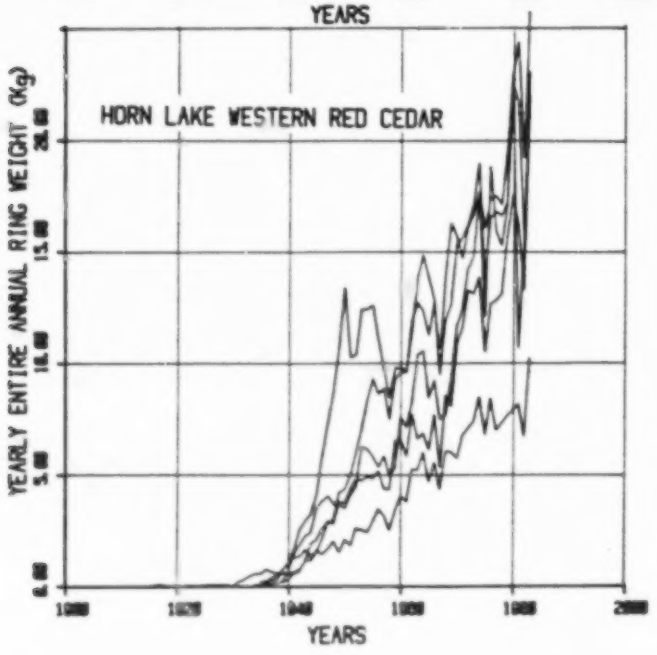

WELLS GRAY PARK LODGEPOLE PINE




WELLS GRAY PARK SPRUCE
YEARLY ENTIRE ANNUAL RING WEIGHT (Kg)
YEARS


CLAUDE LAKE SPRUCE
YEARLY ENTIRE ANNUAL RING WEIGHT (Kg)
YEARS


SHAWNIGAN WESTERN RED CEDAR
YEARLY ENTIRE ANNUAL RING WEIGHT (Kg)
YEARS


HORN LAKE WESTERN RED CEDAR
YEARLY ENTIRE ANNUAL RING WEIGHT (Kg)
YEARS

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